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A GPSS II SIMULATION MODEL OF A BRIGADE RIVER CROSSING OPERATION

A THESIS

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The Faculty of the Graduate Division

by

James J. Waldeck

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A GPSS II SIMULATION MODEL OF A

BRIGADE RIVER CROSSING OPERATION

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Chairman

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GLOSSARY

BATTALION: A unit composed of a headquarters element and two or more companies (Infantry) or batteries (Artillery) (6).

BRIGADE: A unit which is smaller than a division and to which battalions and smaller units are attached as required for operations (6).

COMPANY: The basic tactical and administrative unit in most arms and services of the Army. A company is on a command level below battalion and is equivalent to a battery of artillery (6).

CROSSING AREAS: Crossing areas are designated to facilitate the flow of troops and equipment across the river obstacle by surface means. The crossing area includes the crossing area near bank (CANB), the crossing area far bank (CAFB), the crossing sites, the space required for bridge and raft construction and operation, and the area required for convoy dispersal (9).

DISPERSAL AREAS: Dispersal areas are designated within the crossing area along roads to the bridge and raft sites. They provide space where vehicles can be halted and dispersed to avoid congestion on access roads to the sites when the vehicle flow has been disrupted or when there is a reduction in the capacity of the bridges, rafts, or ferries (9).

DIVISION: The division is a tactical unit or formation which combines in itself the necessary arms and services required for sustained combat. The division is larger than a brigade and smaller than a corps (9).

ENGINEER EQUIPMENT PARKS: Engineer Equipment Parks are areas reserved near bridge and raft sites for the assembly of engineer equipment required for the construction of the crossing equipment (9).

LINE OF DEPARTURE: The Line of Departure (LD) is a line ordinarily located on or behind the last available terrain mask which can be reached without exposure to hostile observation and small arms fire. It is designated to coordinate the departure of an attack (6).

PHASE LINE: The Phase Line (PL) is a line normally located on or near a terrain feature extending across the zone of action. The Phase Line is used to control and coordinate military operations (6).

ZONE OF ACTION: The Zone of Action is a subdivision of a larger area. Responsibility for the Zone of Action is assigned to a specific unit for offensive operations (6).

SUMMARY

The brigade tactical river crossing is a complex flow problem involving the movement of troops, equipment, and vehicles from one side of a river obstacle to the other. Present planning methodologies base the rate of vehicle flow on the capabilities of the river crossing equipment allocated to the brigade. This GPSS II simulation model, programmed for the UNIVAC 1108 computer, simulates a specific brigade river crossing operation which reflects current unclassified U. S. Army planning doctrine.

The model structure and computer simulation run output indicate that simulation methodology provides considerably more parameter availability and quantitative data for analysis than does current methodology.

The GPSS II flow diagram of the base model is very analogous to the traditional military symbology which is used by staff officers to depict the operation.

Experimental results indicate the importance of the Mobile Assault Bridge ferries as compared to the M4T6 rafts and Light Tactical Rafts. The results also suggest further experimentation should be conducted to determine the tactical formation required to achieve acceptable vehicle densities in the crossing areas.

CHAPTER I

INTRODUCTION

Statement of the Problem and Objectives

This thesis concerns the formulation of a realistically structured GPSS II simulation model of a tactical military operation -- a Mechanized Infantry Brigade river crossing. The basic model is a synthesis of various unit sub-models, each depicting a sub-organization of the brigade. The primary objective, therefore, is the model formulation and validation. Ancillary objectives are to determine the adequacy of current U. S. Army river crossing doctrine and to demonstrate, by the model structure and simulation language, how this specific model might be used in U. S. Army service schools as an educational device to promote a better understanding of simulation. Specifically, it will demonstrate how a unit staff officer can, through simulation, clarify and depict courses of action prior to making a staff recommendation.

Background

Despite recent technological advances in helicopter design and capabilities, the majority of a military organization's surface vehicles are still used on the ground during tactical movements. The primary combat vehicles of the mechanized division and brigade are the main battle tank and the armored personnel carrier. Both possess loaded tactical weights (105,000 and 22,495 lbs, respectively) exceeding the lift capabilities of the largest helicopters, the CH-47A and CH54A (18,900 and 18,565 lbs, respectively), in the Army inventory (32). Although the helicopter has significantly freed the infantryman from his traditional two-dimensional battlefield, it has not yet provided a means to transport a mechanized unit's primary fighting vehicles about the battlefield. Thus, the military operation, the tactical river crossing, still exists as a perplexing tactical problem; a complicated maneuver which is, by its nature, very dangerous when executed in the face of a determined defender and potentially vulnerable under any circumstance.

Current U. S. Army doctrine divides river crossing into two types, hasty and deliberate. A hasty crossing is one which can be implemented as an extension or continuation of an attack. It is characterized by speed, surprise, and a minimum concentration of personnel and equipment. A deliberate crossing entails a detailed concentration of supplies, equipment, and personnel, and the extensive use of specialized river crossing equipment. It is conducted when forces must resume the attack after securing the near bank of a river, or whenever a hasty crossing fails. All crossings involve detailed planning to ensure troop dispersion in the crossing area, rapid crossing operations, and the maximum utilization of all crossing systems. The river crossing plan, when applicable to the nuclear environment, should provide for multiple crossing on a wide front with minimum delay and buildup of supplies and equipment (8). The purpose of all river crossing operations is to move an attacking force across the river obstacle in such a manner that the force may continue its attack or seize objectives which will protect subsequent crossings.

The movement across the obstacle should be conducted as rapidly and as efficiently as possible (9).

Planning a river crossing is complicated and time consuming. The division is the smallest tactical organization possessing organic bridging and rafting equipment. Even so, this equipment is generally insufficient and additional river crossing equipment must be made available to the division from higher organizations such as the corps (7). Planning a river crossing implies selecting the best combination of crossing equipment such that the momentum of the advance, the tactical dispostion, and the tactical integrity of the force will be maintained. In addition to the organic equipment in the division, the additional equipment furnished by corps and army engineer groups can also be used in many configurations. The staff officer's task is to recommend the most efficient way in which this equipment should be used. In other words, he must determine what portion should be used for rafts, bridges, or a combination of the two. The mechanized division is equipped with river crossing equipment listed in Table 1 (31).

Based on the commander's policies and the knowledge of the staff regarding the tactical situation, the staff must formulate crossing plan options which are within the capabilities of the available equipment and then compare these options against the available crossing equipment (9) to determine how each option provides for crossing a given number of vehicles. Some of the factors considered during this evaluation are:

1. Adequate crossing volume to insure mission accomplishment.
2. Vulnerability of crossing equipment to enemy attack.

Table 1. Mechanized Division River Crossing Equipment Options

Equipment	Options	Weight Class
Mobile Assault Bridge (MAB)	1-144m bridge or 2-80m bridges or 4-48m ferries	Class 60
M4T6 Bridging	1-170m bridge or 8-rafts	Class 50
Class 60 Bridging	1-165m bridge or 4-5 rafts	Class 60
Light Tactical Rafts (LTR)	2-LTR's or 1-31m bridge	Class 12

Note: Divisional engineers are equipped with either MAB's or a combination of M4T6 and class 60 bridging. The weight class number represents the loading effect of the vehicle. The effect depends on the vehicle weight, axles, and the rate of movement of the vehicle.

3. Congestion in the crossing area which presents the enemy a lucrative target.

4. Efficient utilization of crossing equipment.

A method used to compare crossing plan options is to list, by equipment type, various crossing capabilities and then to express the crossing capability rate in vehicles per unit time. The total number of vehicles is then divided by this rate to get the total crossing time. An example of a typical crossing option is listed in Table 2.

Table 2. Typical Vehicle Crossing Option Chart

Option	Equipment	Rate	Class	Cumulative Vehicles Crossed			
				H+1	H+2	H+3	...
A	8-LTR	7v/r/hr	12	0	56	112	
	10-M4T6 rafts	7	55	0	70	140	
	4-MAB ferries	14	60	0	56	112	
	0-M4T6 bridges						
	Total Vehicles Crossed			0	182	364	...
B	8-LTR	7	12	0	56	112	
	5-M4T6 rafts	7	55	0	35	70	
	4-MAB ferries	14	60	0	56	112	
	1-M4T6 bridge	400	60	0	0	0	(Opens H+7)
	Total Vehicles Crossed			0	147	295	...

Note: MAB ferries and M4T6 rafts may carry two and one Class 55 vehicles, respectively, or four and two Class 12 vehicles per raft per trip. All crossing equipment opens at H+1 hours.

This crossing option chart does not depict all options, but does represent an initial step in a staff officer's river crossing plan formulation methodology. Subsequent development and analysis of various options eventually enable the staff officer to recommend a specific option to the commander.

Current Limitations

This "traditional" methodology, used in the field and service schools, is essentially a simple mathematical solution to a rather complicated queueing flow problem. One can visualize a tactical unit river crossing operation as a bounded physical system as represented in Figure 1. Unit transactions, which represent vehicles, flow through the system in a manner prescribed by the tactical deployment of units and their rate of movement. This flow is either interrupted or modified by the facilities, in this instance river crossing equipment available to permit the transactions to flow across the river obstacle. Although the "traditional" methodology appears to provide a solution to this problem, as demonstrated historically by actual operations, it does not provide the formulator an analogue of the system. The system performance, measured by such quantitative factors as vehicle density in the crossing area, queue sizes at crossing sites and dispersal areas, and river crossing equipment utilization, cannot be demonstrated by the present methodology in sufficient detail such that a quantitative analysis of each river crossing option is permissible. At best, it would appear that a staff officer can merely state which option may provide an optimum rate of flow.

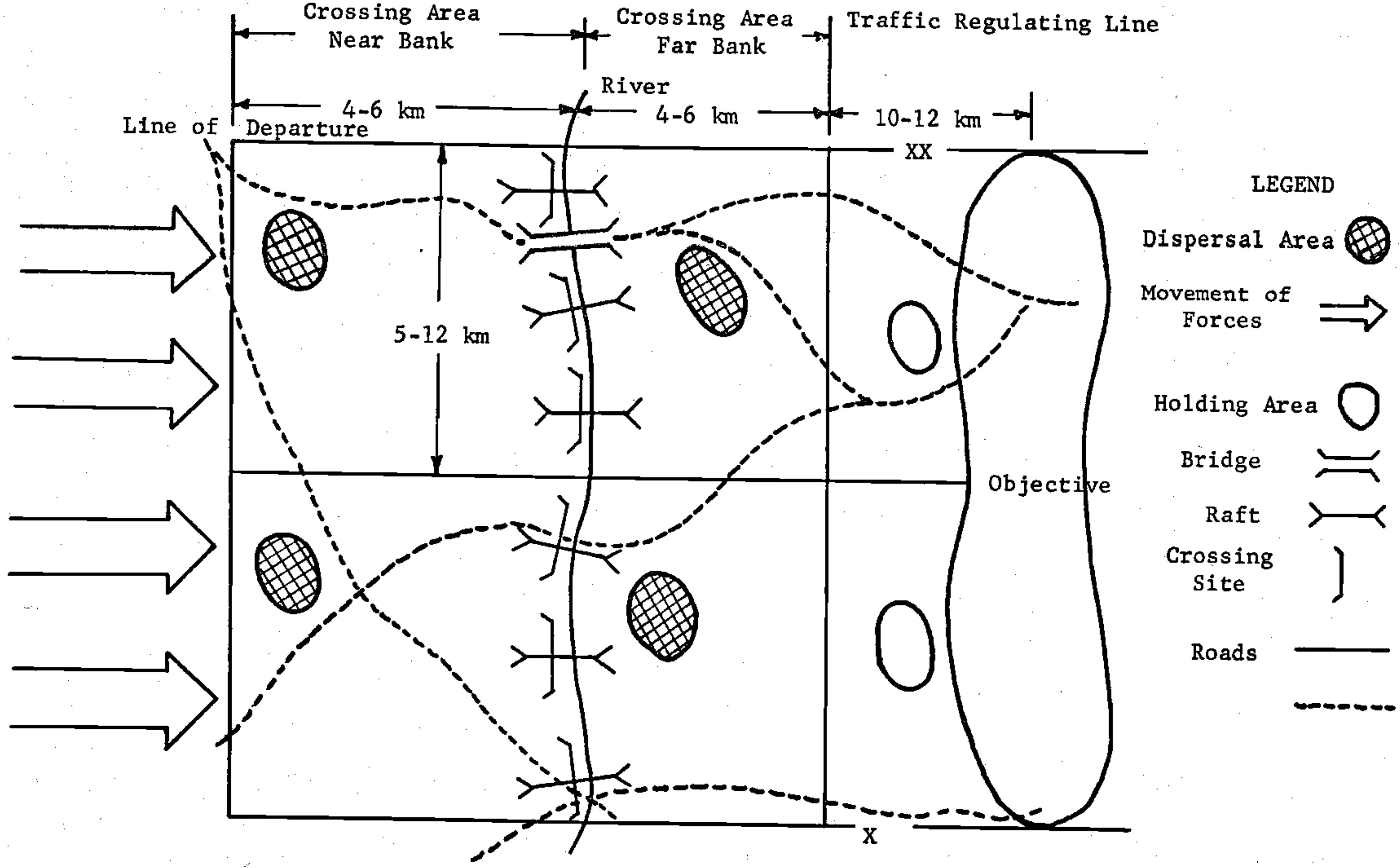

Figure 1. System Model Boundaries (Brigade Zone of Action)

Purpose of Research

The limitations of the current river crossing planning methodology can be lessened, at least in the service school environment, by a new methodological approach to the problem. It is the purpose of this research to demonstrate how a simulation model of a mechanized brigade river crossing operation can provide the staff officer a tool by which he can quantitatively analyze a crossing option. The simulation model, written in GPSS II, will realistically depict the flow within the brigade zone of action and will provide the user considerably more information than is presently available by "traditional" methodology. It is felt that the model will also enable potential users to gain an appreciation of simulation and will provide an incentive for increased demand at lower echelons within the Army for this Operations Research tool.

Methodology, Scope, and Limitations

One of the initial obstacles this research intends to overcome is the general tendency of managers to dismiss the fact that simulation is a valuable planning tool. As mentioned in (27), several reasons exist for this difficulty.

1. Managers (Chiefs of Staff and Commanders) do not understand the simulation.

2. A manager might perceive the simulation as a threat to his job security.

3. Simulation results are not applicable to the problem at hand.

4. A manager does not have time to listen to the simulation analyst's story.

5. The simulation may not represent the problem in a recognizable way to the manager.

One possible way to alleviate these difficulties is the formulation of a simulation model which is analogous to the real world system. Another way to eliminate such difficulties is the formulation and programming of the model by the user. This technique solves the user-programmer interface communications gap, but it also assumes that the user can program (23). The use of a simulation programming language such as GPSS greatly enhances this approach. Simulation programming languages such as GPSS have contributed to the success of simulation techniques by their programming convenience, concept articulation, and their ability to be understood by managers (17).

Schmidt and Taylor (24) state that the problem of constructing a simulation model of a real world system in FORTRAN, or any general purpose language, requires a great deal of effort and can become an arduous task. Special purpose languages were therefore developed to eliminate a major portion of this problem. GPSS, a transaction flow language, is especially appropriate for a simulation model representing a river crossing operation. It was written for users with little or no programming experience (15) and the flow charts used to formulate the program are, with little explanation, very understandable to uninitiated or skeptical managers.

The system to be modeled is based on the 1968-69 U. S. Army Command and General Staff College (CGSC) instructional problem M6440, Deliberate and Hasty River Crossings, and the U. S. Army Infantry School (USAIS) problem BQC 74/1, River Crossing Operations, 1970-71. Both problems discuss and demonstrate the "traditional" methodology in formulating the river crossing plans. As the most detailed data are contained in the CGSC problem, it was used in this work as the model base for validation. Specific subunit employment for all units below brigade in size, such as battalions, is based on doctrine used by the USAIS problem. The model boundaries, represented in Figure 1, depict one of the two committed brigades discussed in the CGSC division problem. The base model, a synthesis of the unit submodels, represents one of the two committed brigades discussed in the CGSC problem and is depicted in Figure 1. Each submodel represents a specific unit as deployed in the CGSC problem and as it reflects U. S. Army river crossing doctrine. The following assumptions have been made:

1. The brigade is committed in a conventional, general war environment and is conducting a hasty river crossing.

2. Enemy contact is light and intermittant.

3. Rates of movement are based on day movement through open terrain.

4. Battalion-sized units occupy and are uniformly distributed throughout a square kilometer area.

5. River crossing equipment capabilities are based on those used in the CGSC reference instructional problem (29). The following general assumption has been made.

Vehicle and river crossing equipment technical data, tactical unit speeds, and deployment configurations are realistic insofar as they are portrayed in U. S. Army training and war game publications (30,10,33,31, 29,9,32).

The general method of procedure in this research was accomplished in the following stages.

1. An analysis of the system, an establishment of boundaries, and a detailed assignment of type vehicles to specific units was accomplished.

2. A general schematic of the flow, similar to Figure 1, was constructed and a representative subunit's flow was formulated in terms of a GPSS flow chart. This subunit flow was then simulated on the computer and results validated by data contained in the CGSC base problem.

3. The base model, structured in a manner analogous to the real world system, was formulated, translated into a GPSS flow diagram, and subsequently validated.

4. An analysis of results determined the useful data obtained from the base model. These data were then compared to the data presently available from the traditional analytical procedures. The analysis of these data was oriented towards the stated research objectives.

Two limitations concomitant with this procedure should be stated. The most significant scientific limitation is the lack of real world empirical data. System parameters such as interarrival times and unit vehicular distributions are based on data contained in U. S. Army training and war game publications and can be used only with a note of caution. The cost of conducting a brigade river crossing maneuver is, of course, a significant constraint which precludes sampling experiments. Thus, the system parameters chosen are the most reliable of those unclassified parameters available and are assumed to be realistic. A second limitation relating to the validation problem is that the size of the computer program resulted in a long run time, approximately seven minutes on a UNIVAC 1108. The number of runs required for statistical validation was judged excessive and resulted in financial limitations being placed on subsequent experimental runs. However, as Naylor stated in (21), "The problem of verifying simulation models remains today perhaps the most elusive of all the unresolved problems associated with comparable simulation techniques." In that the objectives of this research are to demonstrate the potential of simulation and its applicability more than to conduct a specific scientific experiment, it is believed that these two limitations do not significantly detract from the stated research objectives.

Literature Survey

As Dalkey (3) stated in 1967, several hundred major military simulation projects had been carried out in the United States since 1964. Subsequently, many refinements to these projects and new, more extensive projects have been initiated. An extensive literature search of all military problems being investigated by simulation techniques was beyond the scope of this research. This survey was, therefore, limited to recent pertinent literature of simulation in general and simulation studies or projects associated with land combat.

Simulation as defined by McLeod (19), "The art of representing some aspects of the real world by numbers or symbols which may be easily manipulated to facilitate their study," agrees with the military definition and usage contained in (30). However, the term war game does not, technically, imply simulation. A war game, which can be a simulation, implies manipulation of two or more opposing forces (30). Hence, all military simulation models involving maneuver forces are not necessarily war games. The base model developed in this research is such a model and was developed to represent a real world system.

A great deal of military simulation has been accomplished by The Rand Corporation. Kiviat (18) discussed simulation rationale, model construction and uncertainties, and provides a comprehensive list of definitions applicable to the simulation field. In a more recent article (17), he discusses and compares the attributes of general scientific programming languages and special purpose simulation languages. Ginsberg (14), Gordon (15), Haverty (16), and Smith (25) also analyze the pros and cons of using special purpose languages. An extension of this topic, the general problem of simulation acceptance by managers, is investigated and recommendations are offered in (27). In addition to these topics, works by McLeod (19), Gordon (15), Naylor (21), Smith (25), and Schmidt and Taylor (24) offer the simulation practitioner a wealth of information covering the statistical, validation, and general programming methodologies used in simulation.

The U. S. Army agencies primarily concerned with war gaming and computer simulation activities in the land combat field are the Office of the Deputy Chief of Staff for Operations (DCSOPS) and the U. S. Army Combat Developments Command (USACDC). Catalogs from these offices (5,28) and a literature search conducted by the Defense Documentation Center and the Defense Logistics Studies Information Exchange indicate that current simulation studies are quite extensive and numerous. DIVTAG II, a war game being developed by USACDC, is a computer simulation designed to provide a responsive means for evaluating doctrine and organizations in low, mid, and high intensity war. Virtually all aspects of ground combat are simulated for divisional through army group - sized units (28). MAFIA V, the Maneuver and Fire Analyzer, is a closed, time-step simulation which assists force planners in analyzing various factors that affect the capabilities of combat units. MACE, Model for Assessment of Combat Effectiveness, was developed to determine the feasibility of computer simulations as a tool for evaluating division combat effectiveness (28).

Research Analysis Corporation (RAC), although not a part of the Army, is a Federal Contract Research Center and has contributed significantly to simulations of land combat (5). ATLAS, A Tactical, Logistical, and Air Simulation, was developed in 1969 to assist the military planner to evaluate the requirements for military forces. The Theater Battle Model, TBM-68, is a very large scale computer simulation war game designed to simulate a tactical environment realistic enough to serve as a basis for testing military contingency plans.

It is interesting to note in (5) that approximately one percent of the operational games and simulations are written in a special purpose simulation language, whereas approximately sixteen percent of the models under development are being programmed in either GPSS or SIMSCRIPT.

Special purpose simulation languages have, however, been used for military simulations rather extensively by military graduate students at civilian institutions. Works by Davis (4), Faulkender (11), Meyer (20), and Abele (1) demonstrate the applicability of DYNAMO as a simulation tool for the military practitioner. Davis approaches the division tactical river crossing problem with an extensive DYNAMO model which is very detailed and comprehensive. However, unlike GPSS, DYNAMO requires considerable more effort from the novice to understand. The typical DYNAMO flow chart is not as analogous to military symbology as are similar GPSS flow charts. Yet, the potential of DYNAMO or the use of the Industrial Dynamics philosophy as a research tool for the military problem is unquestioned. Several other theses by Boles (2), Gibson (13), and Steine (26) demonstrate the applicability and ease of GPSS as a programming language to simulate air defense, logistics, and aircraft maintenance problems.

CHAPTER II

A TYPE SUBMODEL

General

The purpose of this chapter is to demonstrate to the computer simulation novice--a manager or staff officer whom a practitioner must convince--the analogy between the military symbology used to represent flows in a river crossing operation and the GPSS II flow diagram used to construct the computer simulation model. Quantitative factors and parameters available for analysis in the simulation model which are not normally considered in the traditional methodology will also be identified. It is assumed that the novice possesses a rudimentary understanding of the GPSS II logic, blocks, and system variables contained in (12).

The system depicted in Figure 1 consists of unit submodels which represent specific tactical units of the brigade. One such submodel, a mechanized infantry battalion, is illustrated by the flow diagram in Figure 2. The battalion's vehicles are created in a manner to simulate their actual ground deployment and rate of movement. These parameters are based on data contained in (9), and enter the system at the line of departure. Amphibious vehicles move to the crossing sites, cross the river obstacle, and proceed to their objectives on the far bank. Non-amphibious vehicles move to the dispersal area and to specific crossing

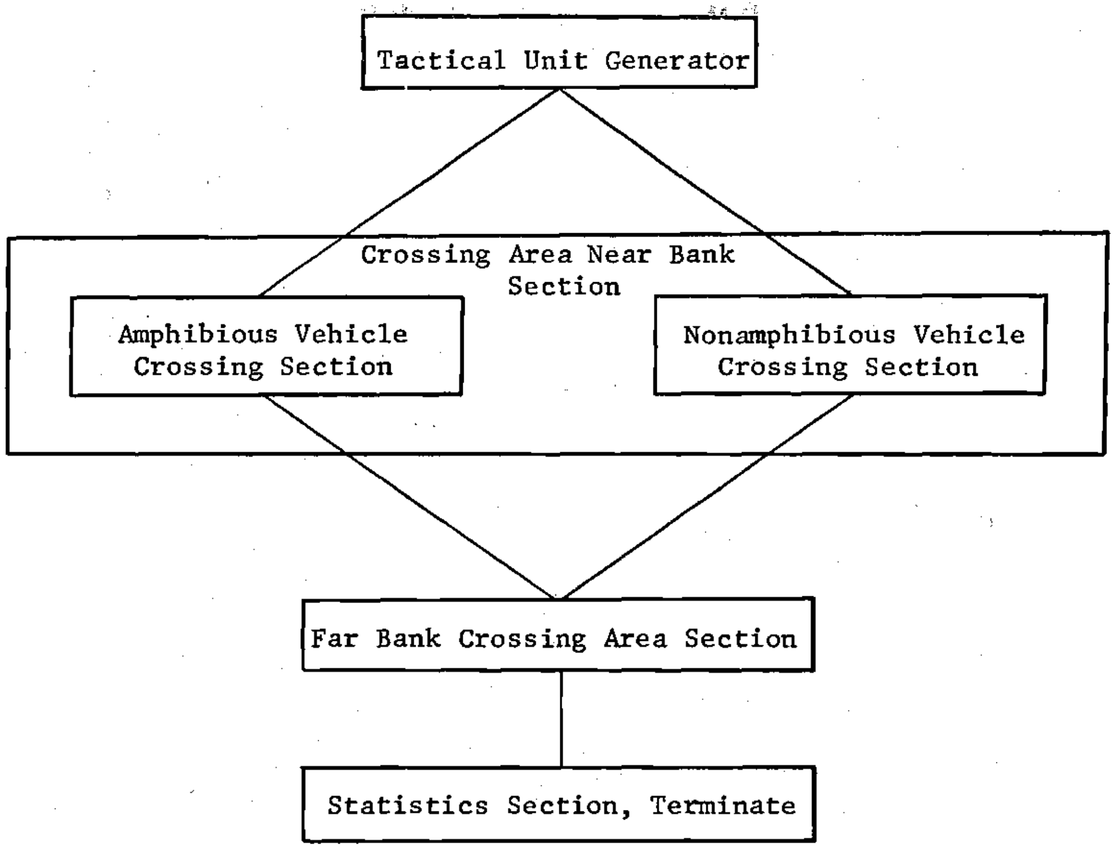

Figure 2. Submodel General Flow Diagram

equipment sites. Class 12 vehicles may use either LTR, M4T6, or MAB rafts; larger vehicles may use either the M4T6 or MAB's. The equipment descriptions are contained in Appendix A.

Tactical Unit Generator Section

The tactical unit generator initiates a unit's vehicles and introduces them as transactions into the model. Each transaction represents one of four vehicle types.

Table 3. Simulation Model Vehicle Types

Vehicle Code	Weight Class	Type Vehicle
C1		Amphibious
C2	Cl 12 < C2 ≦ Cl 60	Heavy tracked
C3	Cl 12 < C3 ≦ Cl 60	Heavy wheeled
C4	C4 ≦ Cl 12	Light and medium

The vehicles are generated in a desired sequence and are assigned a desired rate of movement and interarrival time. The transactions, with these parameter assignments, are initiated in a manner analogous to the actual ground deployment. Figures 3 and 4 depict a battalion advance in military symbology familiar to all operations staff officers. As indicated in (9), the battalion vehicles are assumed to be uniformly distributed throughout a square kilometer. Figure 4 represents a possible deployment formation. Elements of the combat support company and the three rifle

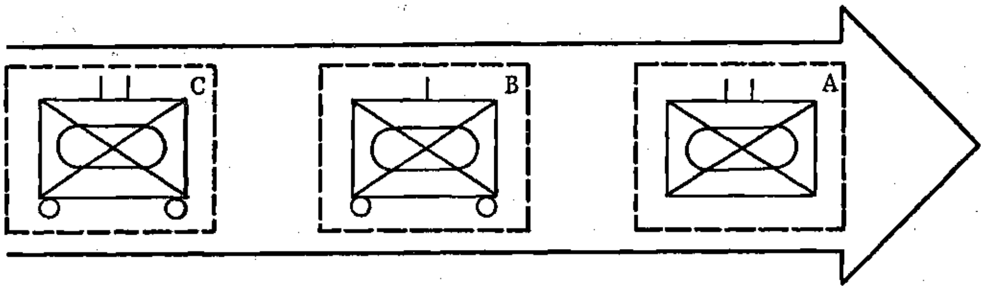

Figure 3. Battalion Axis of Advance

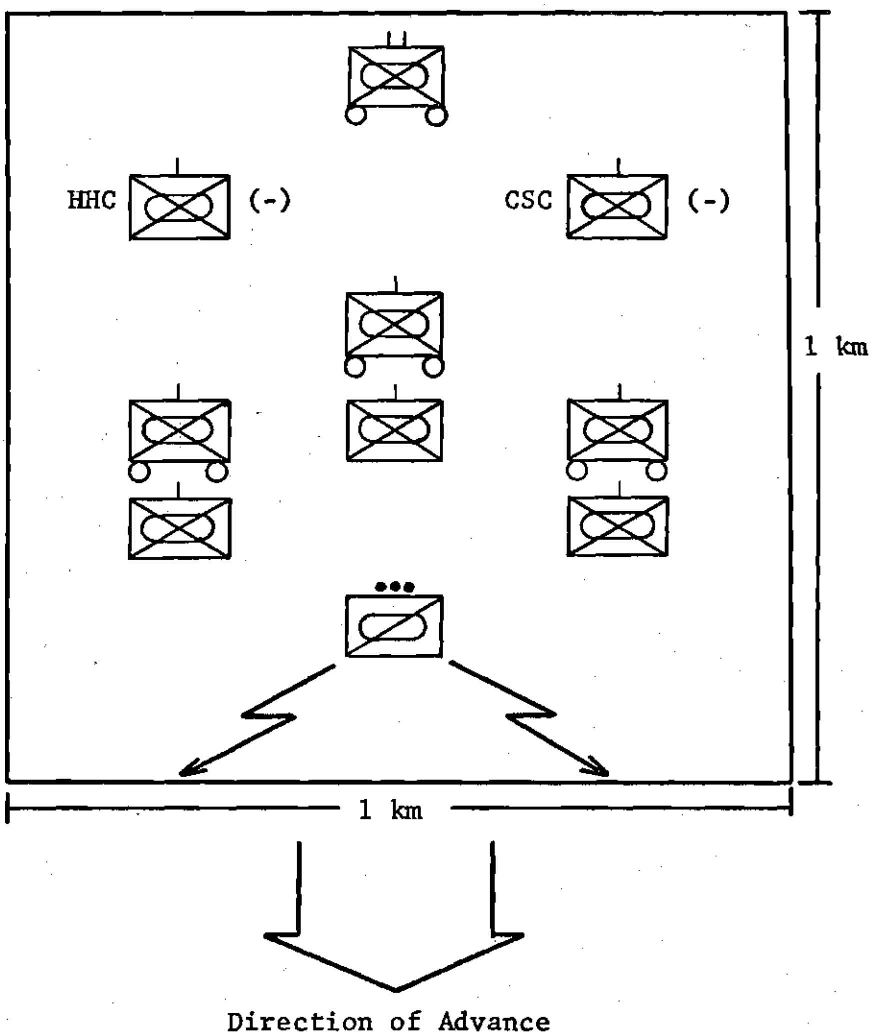

Figure 4. Battalion Type Deployment Configuration

companies comprise the assault echelon. The assault echelon is followed by the company trains and battalion combat trains. The GPSS II flow diagram analogous to Figures 3 and 4 is illustrated by Figure 5. Section D, ORIGINATE and ASSIGN blocks 1 and 2, create 162 transactions every 3 ± 1 seconds, beginning at clock time 0 seconds. The interarrival time of 3 ± 1 seconds was computed by noting that the 162 vehicles--uniformly distributed throughout a square kilometer as illustrated in Figure 4 must traverse one kilometer in:

$$\text{Travel time 1 km} = \frac{(3600\ \text{s/hr})(1\ \text{km})}{(7\ \text{km/hr})} = 514+ \text{ seconds; giving an}$$

$$\text{Arrival rate (AR)} = \frac{162}{514} \text{ vehicles per second; or an}$$

$$\text{Interarrival rate (IAR)} = \frac{1}{\text{AR}} = 3.14 \text{ seconds per vehicle.}$$

Given that the simulation time increment is in one second intervals, a uniformly distributed IAR of 2-4 seconds was chosen. The ASSIGN block identifies each vehicle as a 1-76 Infantry vehicle by assigning the 1-76 identification number, the constant 1 (K1), to each transaction's parameter 6. After K1 is placed in parameter 6, the ALL selection mode sends each transaction to blocks 3-5, in that order. COMPARE block 3 allows the first 82 transactions to enter and sends them to ASSIGN block 6, where each is assigned an identification number, K1, to the vehicle code parameter. K1 identifies each of these transactions as C1 amphibious vehicles. Section A, Figure 5, therefore, represents the vehicles con-

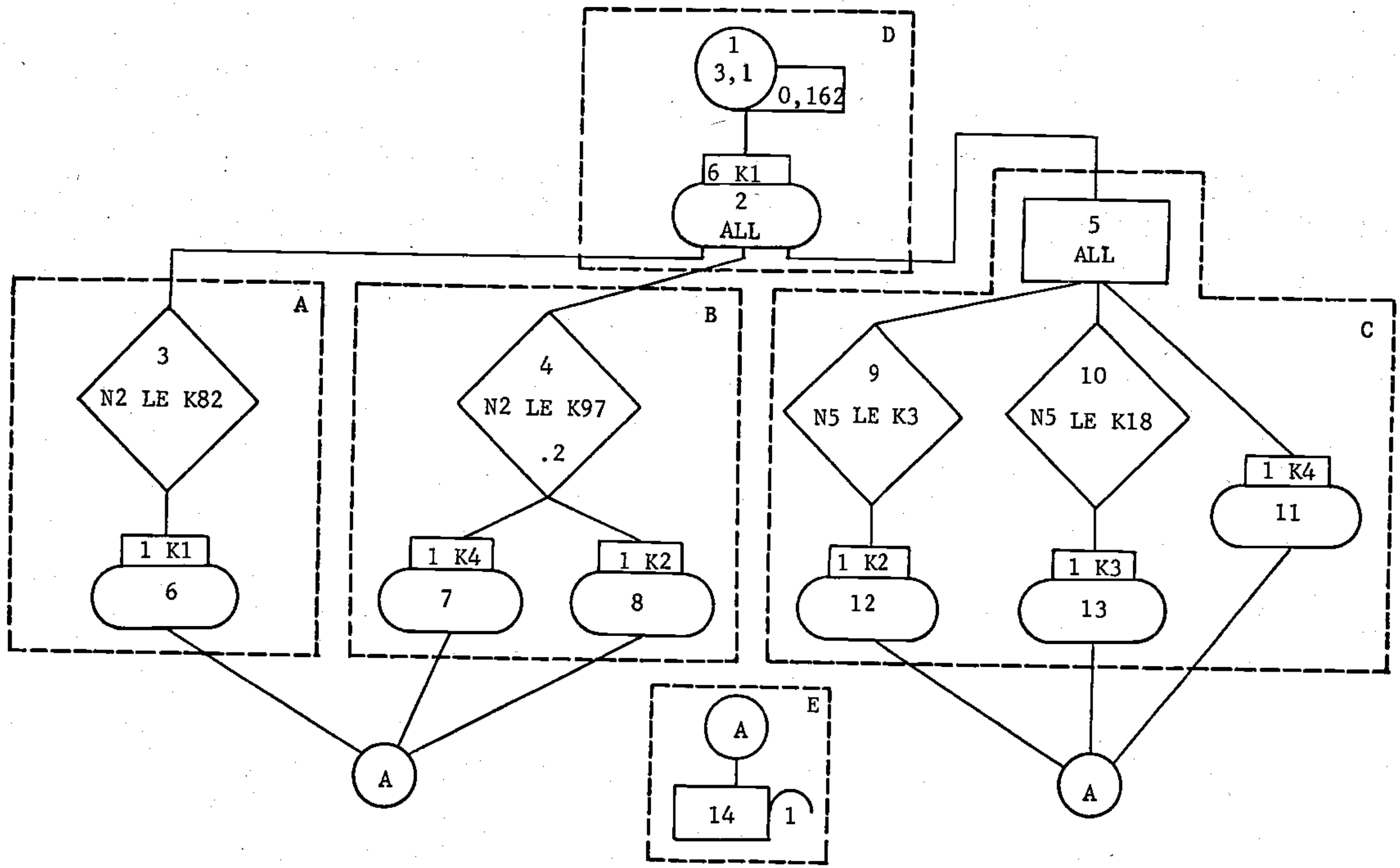

Figure 5. GPSS II Battalion Generator Flow Diagram

tained in Section A, Figure 3. Similarly, Section B, Figure 5 identifies and designates the 15 C2 and C3 vehicles in the company trains (Section B, Figure 3). The battalion combat trains, consisting of three C2 vehicles, 15 C3 vehicles, and 47 C4 vehicles, is depicted by Section C, Figure 3. These vehicles are identified in the corresponding section of the GPSS flow diagram (Figure 5). All transactions, after having been coded according to vehicle type, move to ENTER block 14, storage 1. This storage represents the crossing area near bank (CANB).

Nonamphibious Vehicle Section

Transactions leaving the tactical unit generator section (Figure 2) are separated into two major categories, amphibious and nonamphibious vehicles. A COMPARE block allows all transactions with the C1 identifier in parameter 1 to enter the amphibious vehicle crossing section. All other vehicles, the C2, C3, and C4 vehicles, enter the nonamphibious section.

Figure 6 illustrates the nonamphibious section in military symbology. Vehicles (transactions) enter this section at the line of departure (LD) and move to the dispersal area near bank (DANB). Vehicles are then assigned to one of two subareas within the DANB. One subarea contains all C4 vehicles and the other all C2 and C3 vehicles. The C4 vehicles may use all crossing equipment available, whereas the larger vehicles may use either the M4T6 or MAB rafts. Vehicles are dispatched to the raft sites so that no more than five are enroute to each site. This parameter is selected to represent the control exercised by the Traffic Control Post located at the dispersal area. Vehicles are dis-

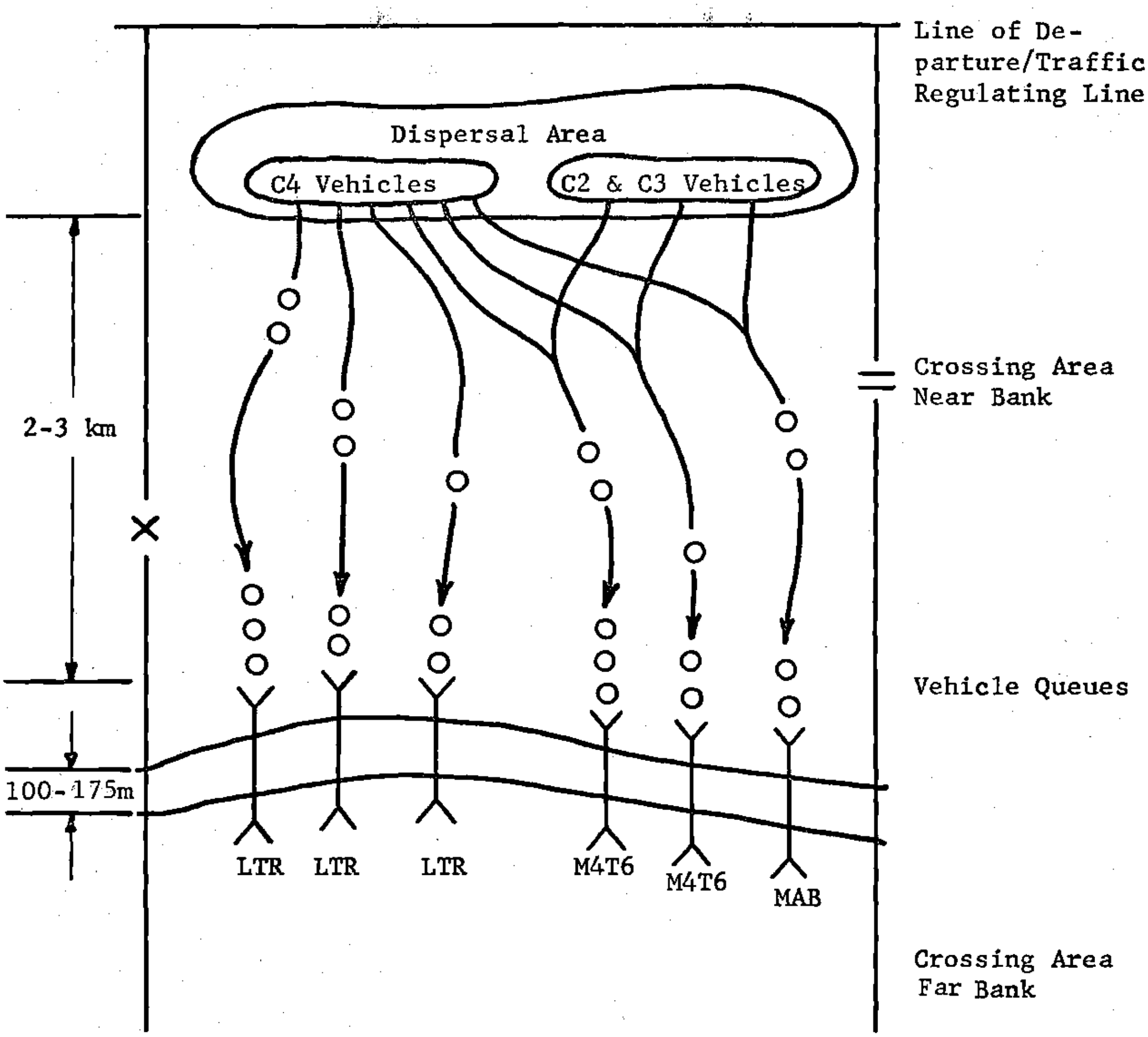

Figure 6. Nonamphibious Vehicle Flow Diagram

patched to control the raft site queues and to preclude unnecessary congestion in the area between the dispersal area and the raft sites. The vehicles move onto the rafts, cross the river, and enter the crossing area far bank (CAFB). If the raft is occupied, the vehicles queue in front of each raft site.

The analogous GPSS II flow diagram establishes the simulation logic and transaction flow and is shown by Figure 7. The LD, or entrance to the CANB, is represented by ENTER block 17's storage 13. Each transaction's parameter 5 is assigned a value of variable 1 by ASSIGN block 18. This value represents the transit time from the DANB to the raft sites and is determined by the following GPSS variable statement:

```
1 VARIABLE   FN1*K3600/P4/K10
```

This is equivalent to the mathematical expression:

Transit time = Distance/Vehicle Rate of Movement

(See Figure 8)

The random number generator selects a uniformly distributed number between zero and one as the function's argument and computes a functional value between 20 and 30. Assuming this value is 28 and that the value in parameter 4 is 7, the assigned rate of movement, the variable statement becomes:

$$\text{Transit Time} = \left(\frac{28}{10}\text{ km}\right)\left(3600\ \frac{\text{sec}}{\text{hr}}\right)\left(\frac{1\text{ hr}}{7\text{ km}}\right) = 1440 \text{ seconds.}$$

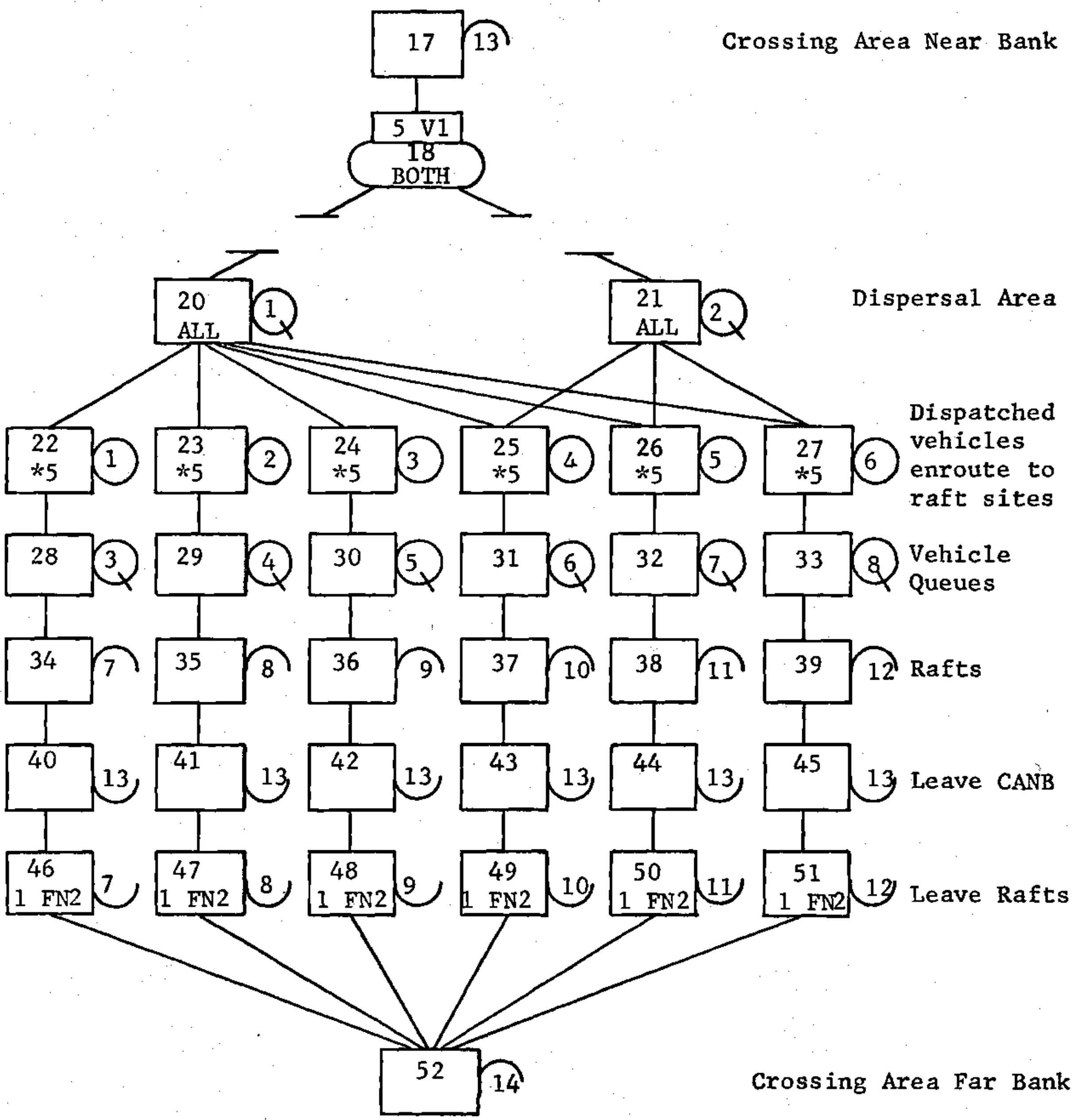

Figure 7. GPSS II Nonamphibious Vehicle Flow Diagram

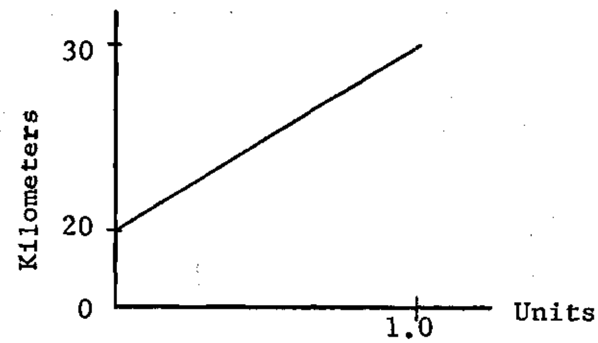

Figure 8. GPSS II CANB Transit Time Function

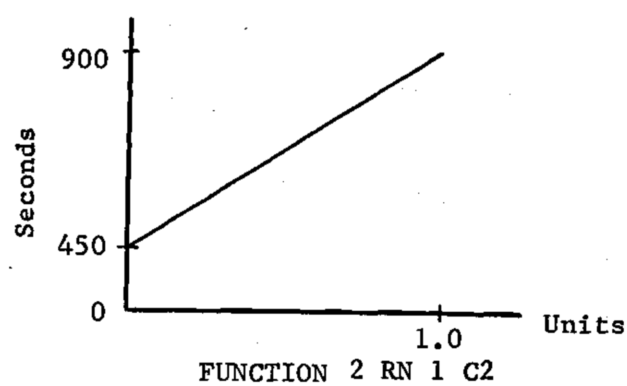

Figure 9. GPSS II River Crossing Transit Time Function

The BOTH selection mode sends the transactions, in turn, to QUEUE 1 and 2, blocks 20 and 21. All C4 vehicles are identified and are permitted to enter QUEUE 1, the C4 subarea. All other vehicles enter QUEUE 2, the C2-C3 subarea. Block 20's ALL selection mode sends the transactions to STORE 1 through STORE 6. These storages represent the terrain between the subarea and raft sites. Similarly, block 21's ALL selection mode sends the vehicles to STORE 4 through STORE 6. Each STORE is assigned a capacity of five to limit the vehicles enroute to the desired number. The transit time, computed by the variable statement previously discussed, is obtained by indirect specification to the value contained in parameter 5.

Transactions move to the raft queues, QUEUE 3 through QUEUE 8; from the queues to ENTER storage 7-12, blocks 34-39, which represent the rafts; and leave the CANB by entering LEAVE storage 13, blocks 40-45. The river crossing transit time is simulated by the product of the mean and the value of function 2 (see Figure 9). Function 2 delays each raft for 450-900 seconds. This delay simulates a 4-8 round trip per hour utilization rate.* ENTER storage 14, block 52, represents the crossing area far bank (CAFB). The CAFB is entered by all transactions as they leave the rafts.

A more vivid analogy between the military and GPSS II symboloby (Figures 6 and 7) is illustrated by Figure 10, a superimposition of

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*The CGSC problem assumes a six round trip per hour utilization rate. The 4-8 round trip per hour uniformly distributed utilization rate is used in the model to more realistically represent the range of this parameter as observed in actual operations.

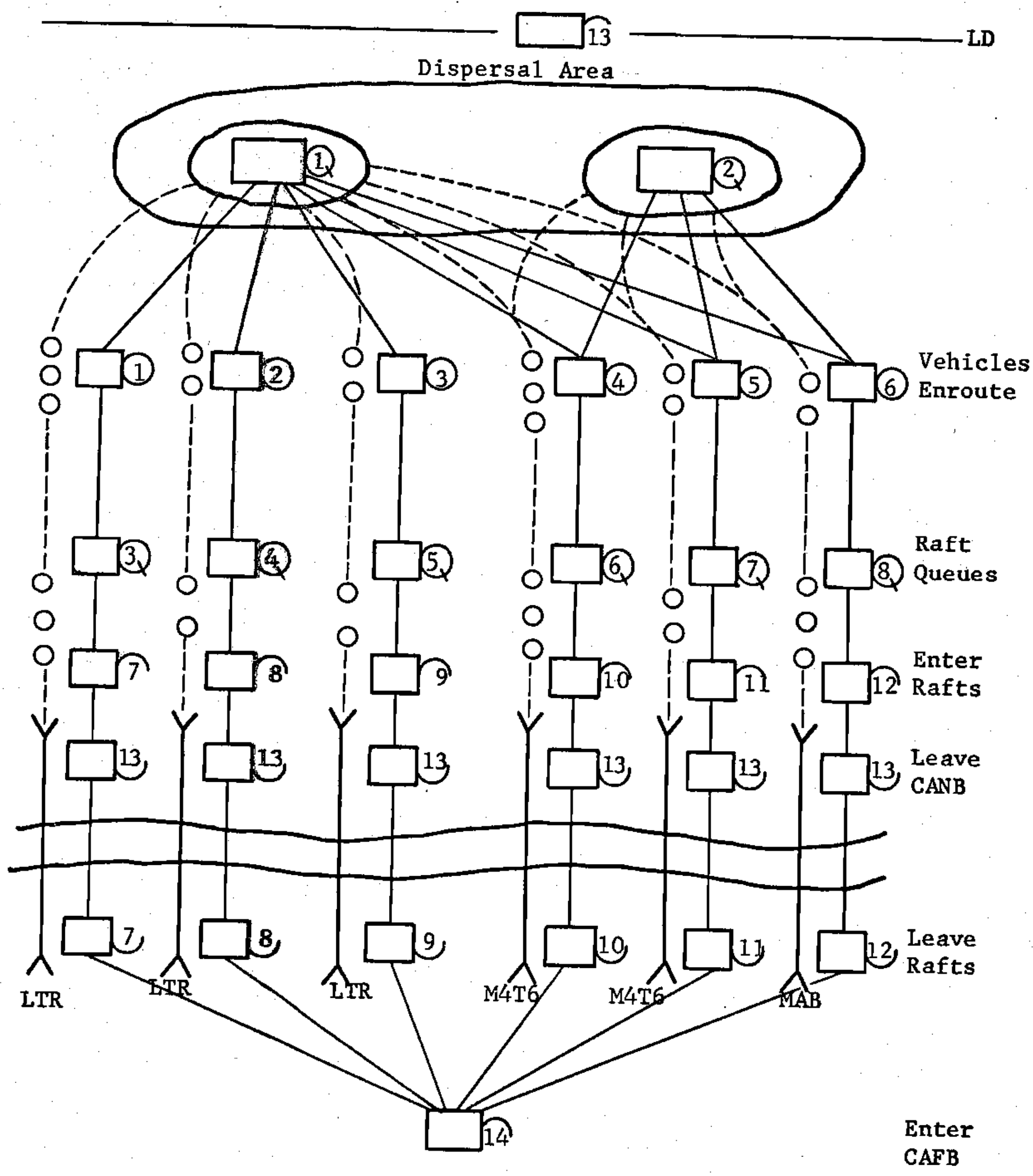

Figure 10. Superimposition of Figures 6 and 7

Figures 6 and 7.

Amphibious Vehicle Section

Figures 11 and 12 depict the Amphibious Vehicle Section of Figure 2. The flow similarities are obvious, but a more detailed inspection of Figure 11 reveals significantly more quantitative information and parameter potential than that available with military symbology. This information and parameter availability is very useful in model validation and enables the practitioner to realistically represent a real world situation with the simulation model.

STORE 20-22, blocks 69-71, depict the three crossing sites available to the crossing force. It is not realistic to assume that all amphibious vehicles enter these sites as they arrive. To do so would assume that ingress to the water is available all along the near bank. The selection of the crossing sites indicates that this is not so, but that ingress is limited to the areas delineated by the sites. This restriction reduces the ingress area width from, for example, a 3000 meter crossing width to the total width of the three crossing sites. This width determines how many vehicles may enter the river simultaneously. If the terrain along the near bank were very difficult, it is realistic to visualize situations where no more than ten vehicles could enter the river simultaneously from each site. The crossing site ingress capacity can be determined by reconnaissance of the river bank. However, once determined, this restriction can be simulated by setting the proper capacity limit for storages 20-22. These capacities limit the number of transactions entering each block. The delay of 8 ± 3 seconds represents

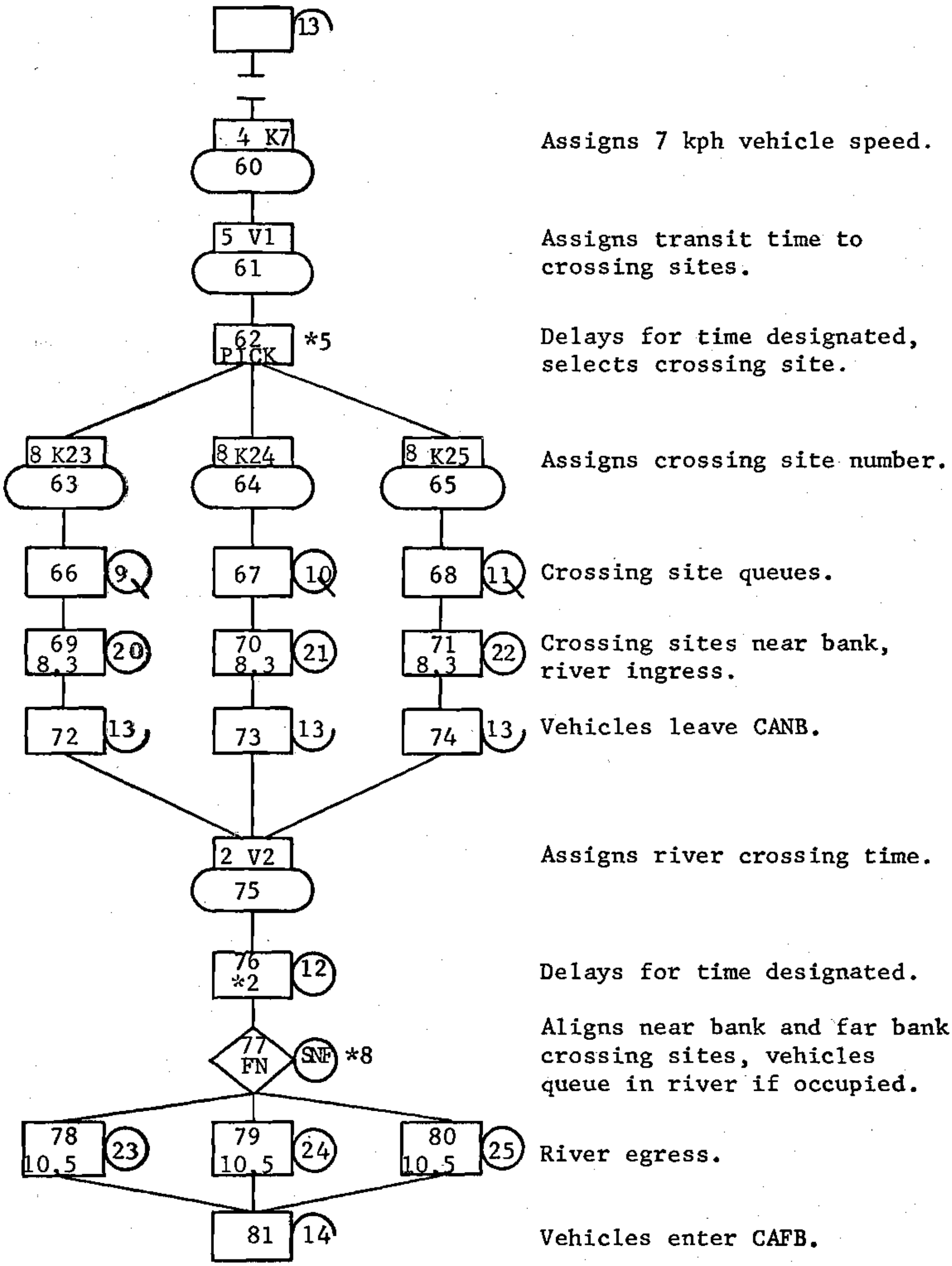

Figure 11. GPSS II Amphibious Vehicle Flow Diagram

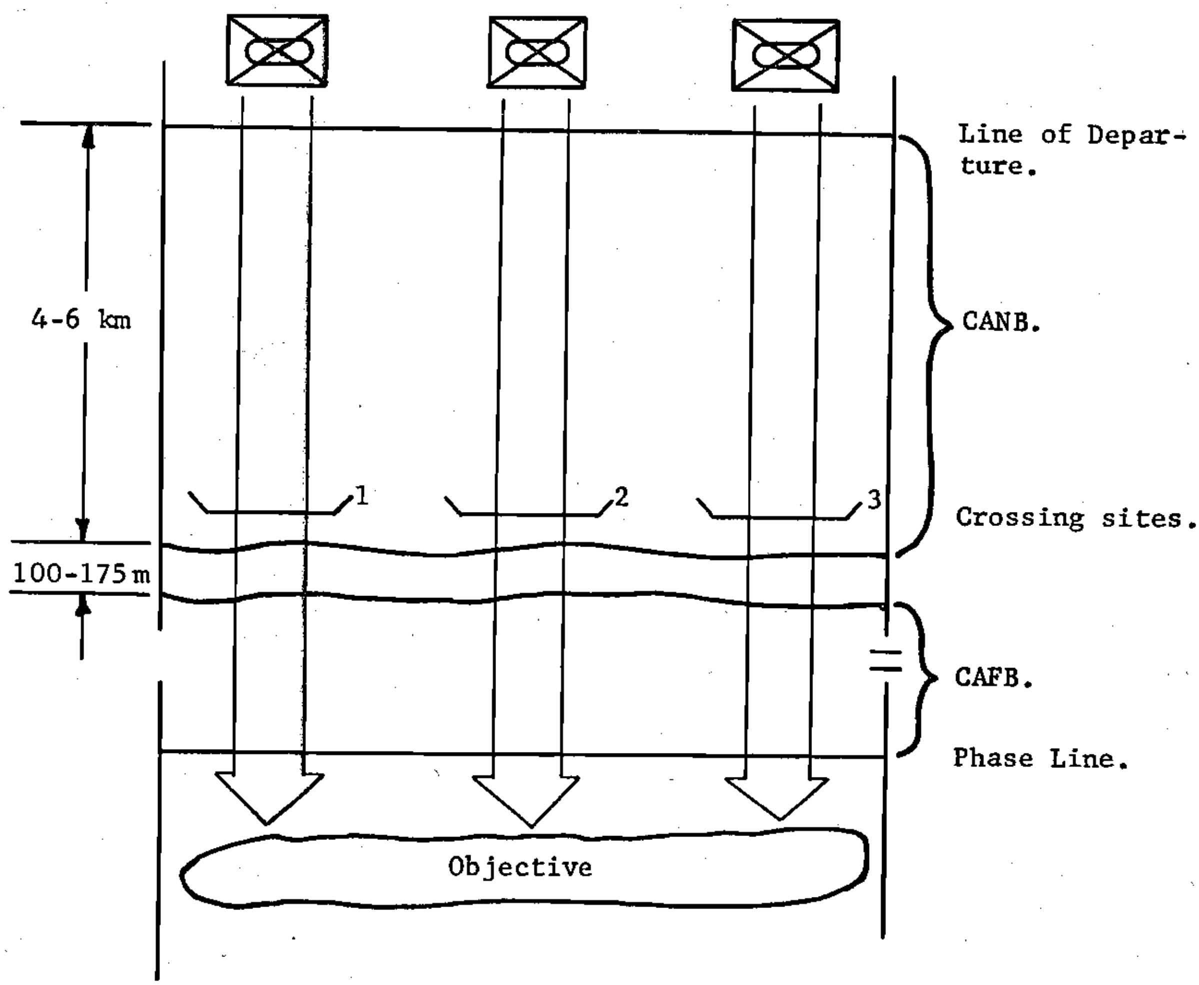

Figure 12. Amphibious Vehicle Flow Diagram

the amphibious vehicles' movement from the near bank edge into the river. The real world situation would also result in queues forming behind each crossing site. This is simulated by QUEUES 9-11, blocks 66-68.

Another problem in an actual river crossing is the annoying situation which does not allow as many vehicles to enter the far bank crossing sites as entered the near bank sites. This can be realistically portrayed in the GPSS II simulation model by adjusting the capacities of the storages which represent the egress sites (STORE 23-25, blocks 78-80). The delay time in these blocks, 10 ± 5 seconds, allows a longer delay to simulate the uphill climb from the river to the far bank. The ingress and egress parameters represent values which affect a vehicle's river crossing time in actual operations. These parameters are not considered in the traditional methodology. The values selected are based on the author's experience and are included to demonstrate the detail which can be structured into the simulation model.

The near bank and far bank crossing site alignment is simulated by blocks 63-65, and block 77. Vehicles entering the river at crossing site 1 (STORE 20) are directed to the corresponding far bank crossing site (STORE 23) by assigning the storage number to parameter 8 of each transaction. As transactions attempt to enter the far bank sites (STORE 23-25), a selection mode FUNCTION, abbreviated FN in the block symbol, assigned to block 77 orients each transaction to the proper far bank site, Figure 13. The value of function 3 is the number corresponding to the block number assigned to parameter 8. This is used as the argument.

River transit time is simulated by blocks 75-77. The value of variable 2 is the quotient of a uniformly distributed river width (100-175 meters) and the amphibious vehicle rate of movement (3-5 kph), Figure 14.

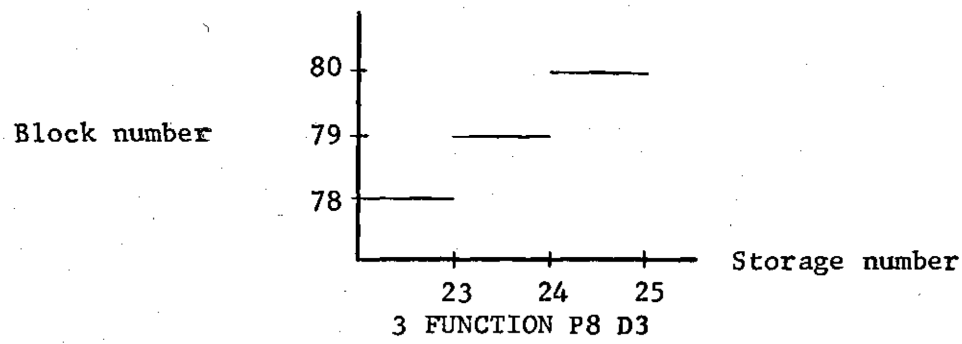

Figure 13. GPSS II Crossing Site Alignment Function

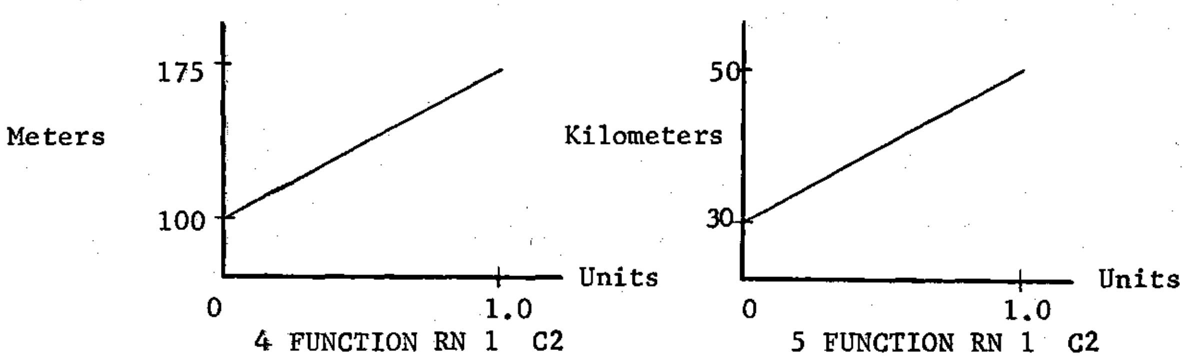

Figure 14. GPSS II River Transit Time Functions

The value of variable 2:

2 VARIABLE FN4*K3600/FN5*K100

is assigned to parameter 2 of each transaction and the delay is effected by indirect specification in block 76. If, after this delay, a crossing site is not full, transactions enter blocks 78-80. However, if a site is full, the transactions queue in the river and enter the crossing sites when space is available.

This option is simulated by block 77, GATE SNF*8. The system variable SNF*8 allows a transaction to enter the block if the corresponding storage number contained in the transaction's parameter 8 (either K23, K24, or K25) is not full. If this test is satisfied, the transaction enters block 77 and is sent to the appropriate far bank crossing site. All transactions then proceed to the CAFB, which is represented in GPSS II symbology as ENTER storage 14, block 81.

Inherent Quantitative Data Availability

The GPSS II flow diagram enables the practitioner to collect, collate, and analyze a large amount of information not available in the traditional methodology. Traffic flow, effects of competition for river crossing equipment, and the simulated system logic may be studied. The computer output may provide information on:

1. the volume of vehicles moving through the system,
2. transit time distribution between selected points within the system,
3. average utilization of critical equipment, and
4. maximum and average queue lengths at selected queues.

Vehicle priorities may be established and the interdependence between selected variables such as queue lengths, vehicle density or rates of vehicle flow, and the transit time for a selected crossing unit to effect a crossing may also be varied and studied (12).

CHAPTER III

THE BASE MODEL

General

The base model is a computer simulation model of the system illustrated in Figure 1. Input to this system are the vehicles of the 1st Brigade, 52nd Mechanized Division. The task organization of the brigade, Appendix B, and tactical configuration, Figure 15, are based on the CGSC instructional problem (29). The base model simulates one specific type of brigade task organization, that depicted in Appendix B; and one type tactical configuration, that illustrated by Figure 15. The CGSC problem served as the base from which all quantitative data were obtained. Time and distance parameters were obtained from topographical map measurements and from U. S. Army war game data (30). The tactical formation and task organization reflect the author's experience and perception of U. S. Army river crossing doctrine as contained in (9, 34, 29, and 8).

The base model is a synthesis of unit submodels similar to that discussed in Chapter II. The general flow diagram of the model is depicted by Figure 16. The Tactical Unit Generator Section (Section A) initiates the units and passes them as transactions to the Main Movement Section (Section B) or the Special Unit Processing Section (Section D). The routing depends on the type unit. Unit vehicle flows are simulated

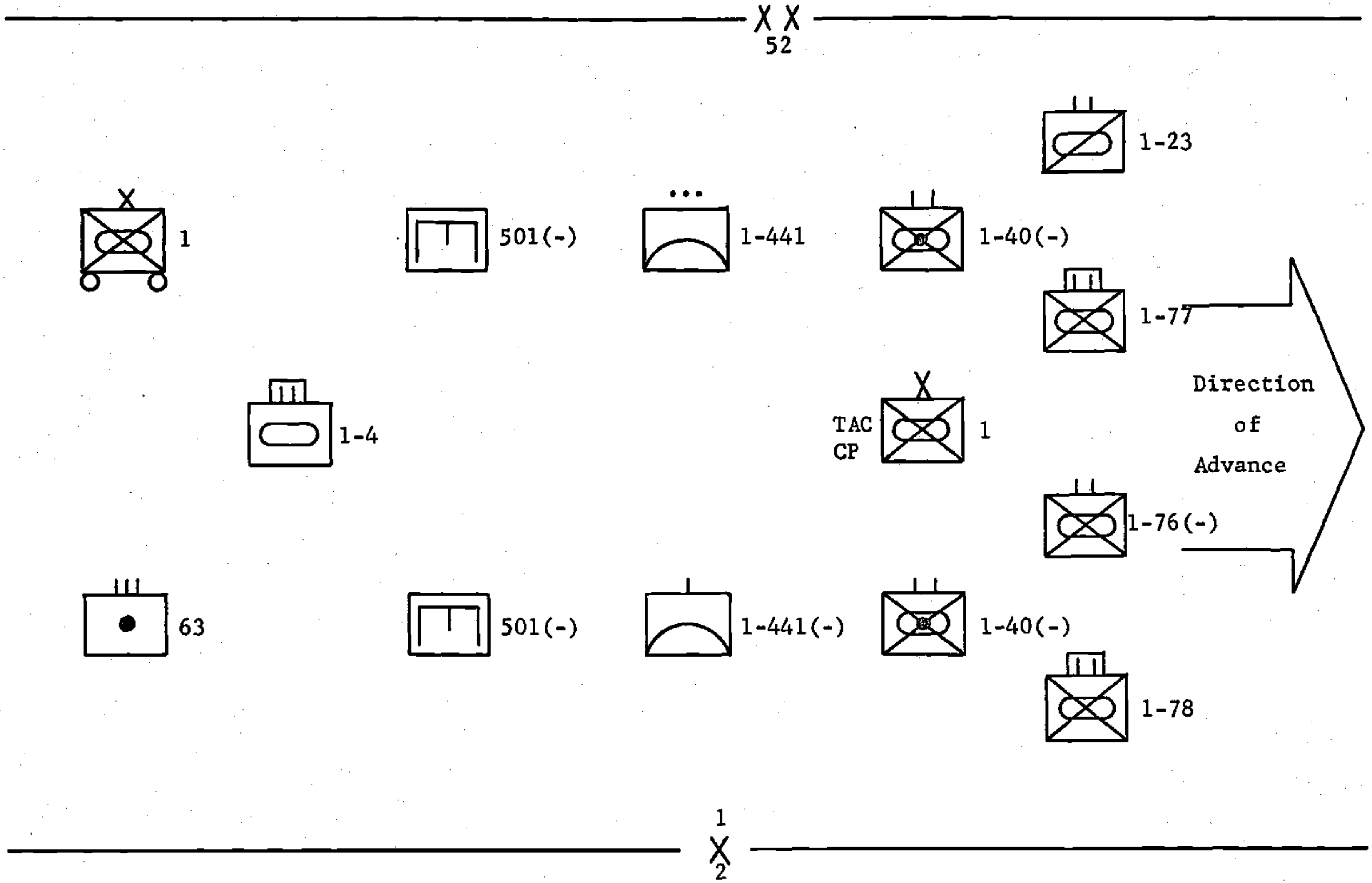

Figure 15. Base Model Tactical Unit Deployment Configuration

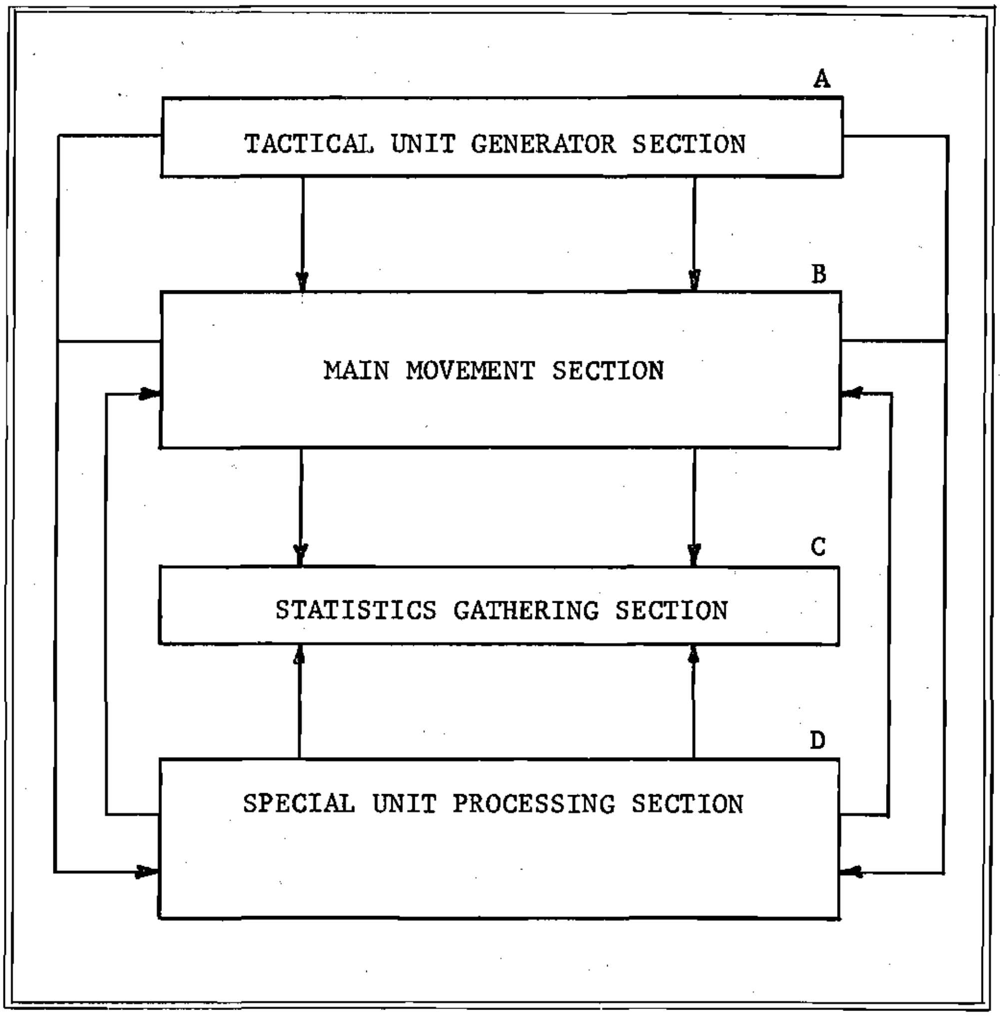

Figure 16. Base Model General Flow Diagram

by these sections through the Crossing Area Near Bank (CANB), across the river, through the Crossing Area Far Bank (CAFB), and onto the objective. After passing through the objective area, unit vehicles are terminated and appropriate statistics are gathered by the Statistics Gathering Section (Section C).

As indicated by the computer program of the GPSS II base model simulation, Appendix C, the model is structured in a manner analogous to the military units it simulates. Achieving this similarity has required a large number of GPSS II blocks. The model contains over 790 blocks and is capable of processing up to 2500 transactions simultaneously. The size of the model precludes listing a complete GPSS II flow diagram. However, a representative flow diagram is contained in Appendix D. Portions of this GPSS II diagram, depicted as superimpositions of the military and GPSS II symbology, will be discussed in detail.

Tactical Unit Generator Section

Each tactical unit's vehicles are initiated by an ORIGINATE or GENERATE block, depending on the time of initiation, and assigned an identification number in parameter 6, the unit identification parameter. Units are referred to in the computer program as U1, U2, and so on. When the code is followed by S or N, such as U4S or U4N, the unit is further identified as to its location in the brigade zone of action. Vehicle identification codes are assigned to each transaction's parameter 1, as was done in the submodel, to designate and identify a unit's C1, C2, C3, and C4 vehicles.

Table 4. Tactical Unit Identification Codes

Unit	Identification Code Assigned Parameter 6
TF 1-78 Inf (U1)	K1
1-76 Inf (U2)	K2
TF 1-77 Inf (U3)	K3
TF 1-4 Armor (U4)	K4
1-23 Cav (U5)	K5
Bde Tac CP (U6)	K6
1-441 Arty (U7)	K7
Engineers (U8)	K8
Trains (U9)	K9
1-40 Arty (U10)	K10
1-651 Arty (U11)	K11
1-652 Arty (U12)	K12

The tactical unit generator blocks are similar to the TF 1-78 Inf ORIGINATE block previously discussed with the exception that the number of transactions initiated differs according to the number of vehicles in each unit. The time of entry of the transactions into the model varies according to the tactical formation. All units crossing the line of departure (entering the system) at clock time zero are initiated by ORIGINATE blocks. Subsequent arrivals are initiated by GENERATE blocks with the proper delay controlled by COMPARE blocks. Subsequent variations in the base model tactical formation are made in the experimental runs, Chapter IV, by manipulating the subunit generator ORIGINATE and GENERATE block parameters. A representative GPSS II flow chart of one unit generator is included in Appendix D.

Main Movement Section

The general flow of the Main Movement Section (Section B, Fig. 16) is illustrated in detail by Figure 17. The section is divided into two major subsections, northern and southern, which receive unit vehicles according to their relative location in the system. Approximately half of the vehicles move through each of these subsections. Transactions enter the Main Movement Section from Section A or D, and are sent to either the northern or southern portions. A unit's vehicles are identified as either amphibious or nonamphibious and are routed to the appropriate simulation model subsection. After effecting the river crossing, vehicles are directed to the CAFB subsection and are either transferred to the Special Unit Processing Section for subsequent movement to the objective area, or to the Main Movement Section for similar routing. As the transactions (vehicles) pass through the objective area, they are terminated from the system and enter the Statistics Gathering Section for statistical compilations. Subsequent discussion will be restricted to the southern portion of the system. This portion is representative of the total system transaction flow and GPSS II logic.

Southern Amphibious Vehicle Flow

The southern amphibious vehicle flow is divided into two main subsections: the flow initiated as the vehicles enter the CANB and cross the river, and the subsequent flow initiated as the vehicles enter the CAFB. The GPSS II flow diagram, Appendix D, illustrates the base

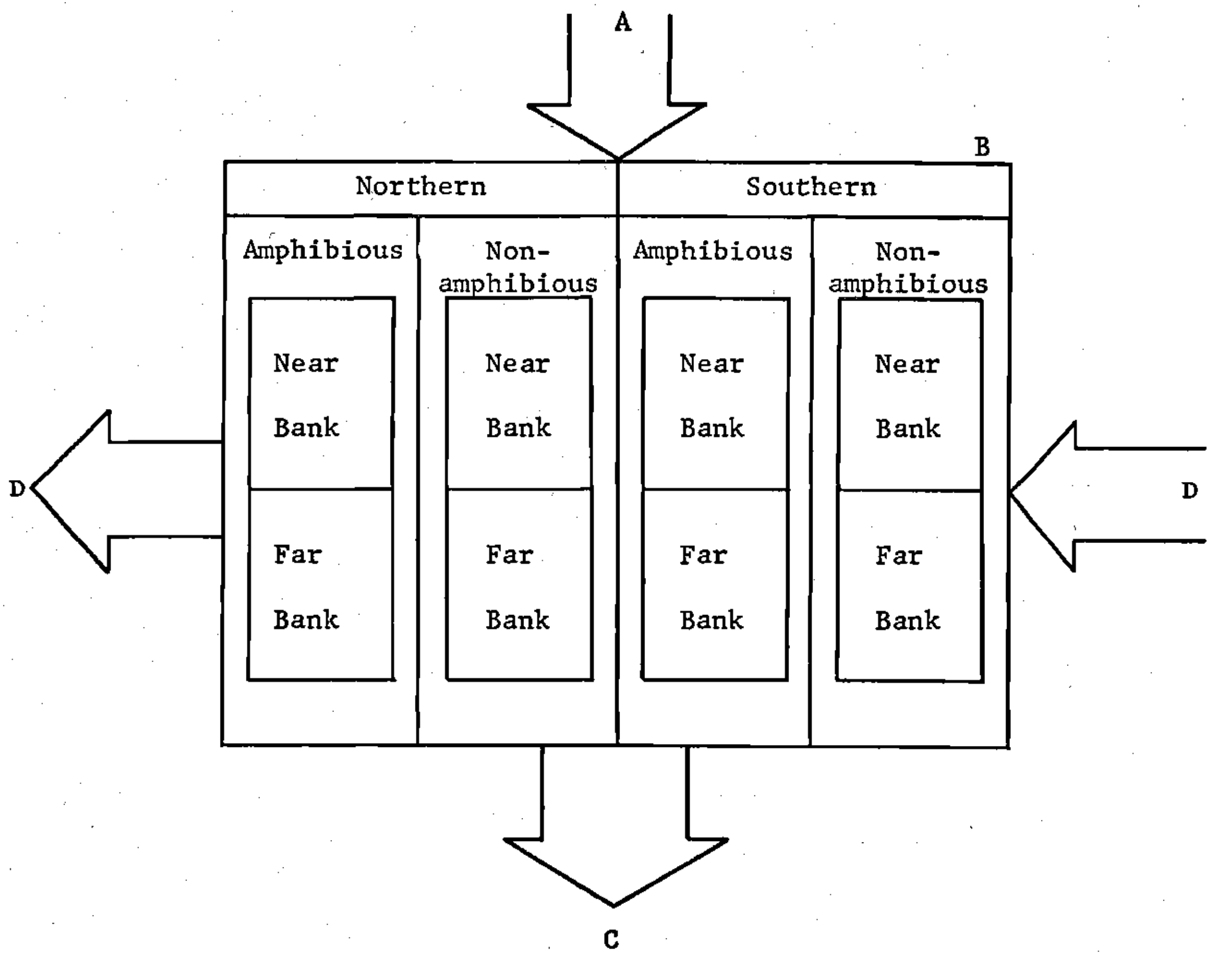

Figure 17. Main Movement Section General Flow Diagram

model simulation logic. The base model CANB flow is identical to the submodel flow, Figure 11, with the exception of the system variable and block number digits.

The CAFB southern amphibious vehicle flow, Figure 18, begins as vehicles enter the far bank and are routed to specific unit flow sections: TF 1-78 Inf (U1) to block 450, and 1-76 Inf (U2) to block 460. These COMPARE blocks allow the C1 amphibious vehicles to enter and the time each transaction enters is placed in SAVEX locations 25 and 26. The SAVEX storage cell values are maintained by the program and are automatically printed in the computer printout at the termination of the simulation run. The vehicles move to the alignment areas (ENTER storage 29 and 30, blocks 452 and 462) and are delayed by GATE blocks 453 and 463 until all vehicles have closed. This realistically represents the tactical unit's reorganization after crossing the river and insures that the unit moves from the alignment area in a proper tactical formation. The formation is reinitiated by GENERATE blocks 456 and 466. The COMPARE blocks following the GENERATE blocks insure that no transaction enters until the alignment areas are full.

Having satisfied the COMPARE statements, transactions leave the alignment area and are assigned a transit time to simulate the delay from the alignment area to the phase line. The value of variable 1:

1 VARIABLE FN1*K3600/P4/K10

is placed in each transaction's parameter 2 by ASSIGN block 470. The time is computed by dividing the vehicle rate of movement (7 kph and contained

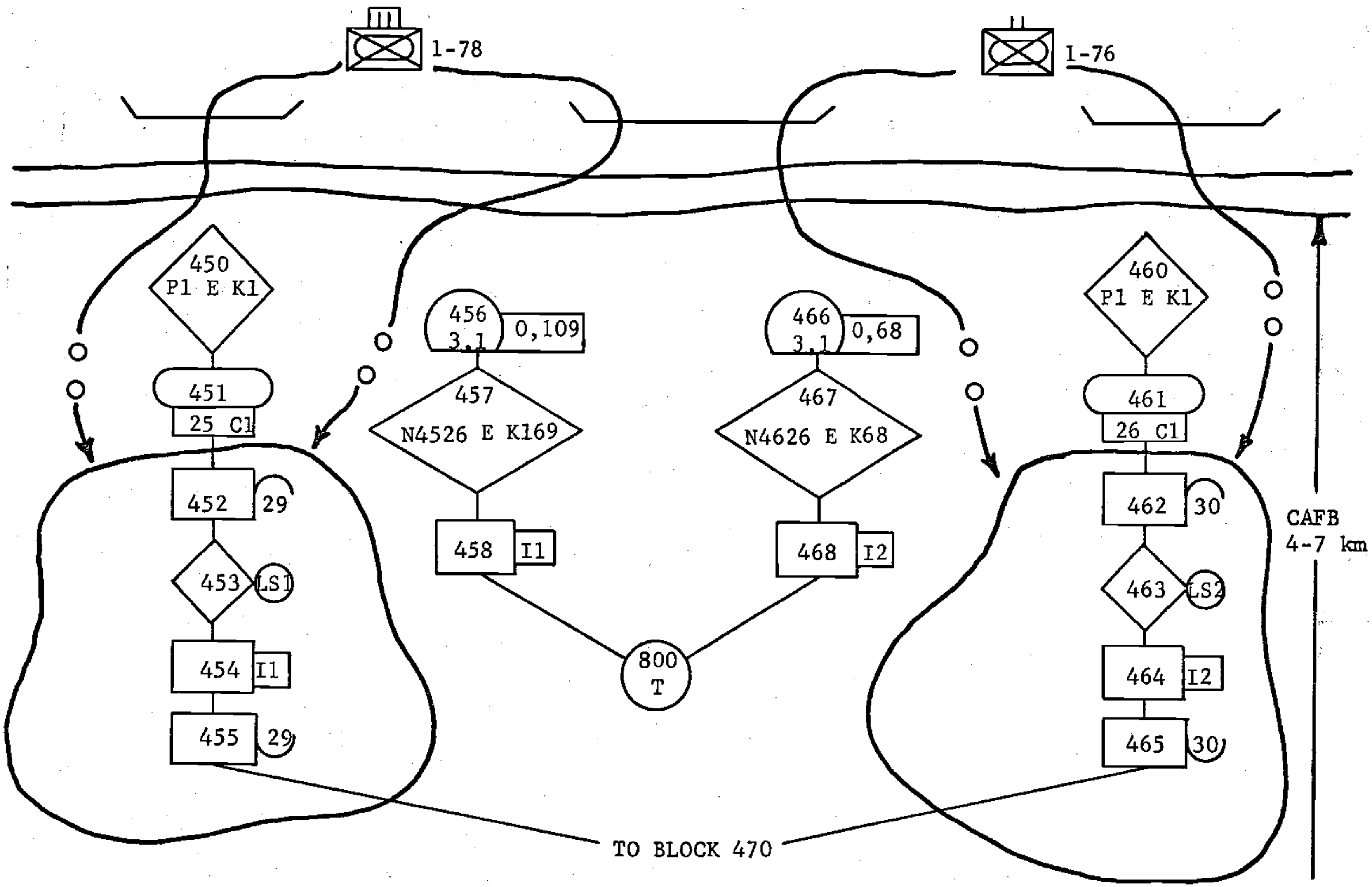

Figure 18. Southern Amphibious Vehicle Flow

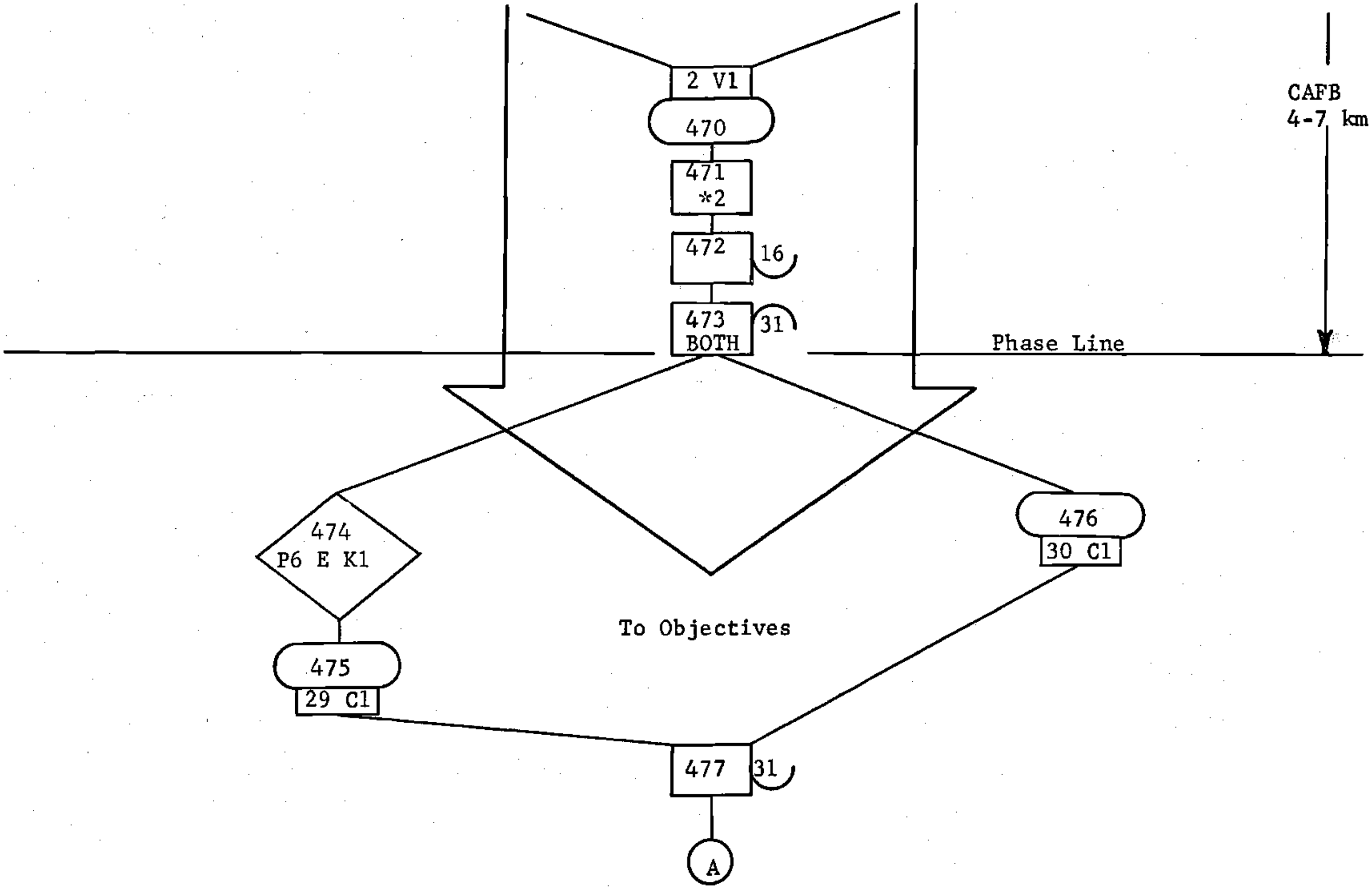

Figure 18. Continued

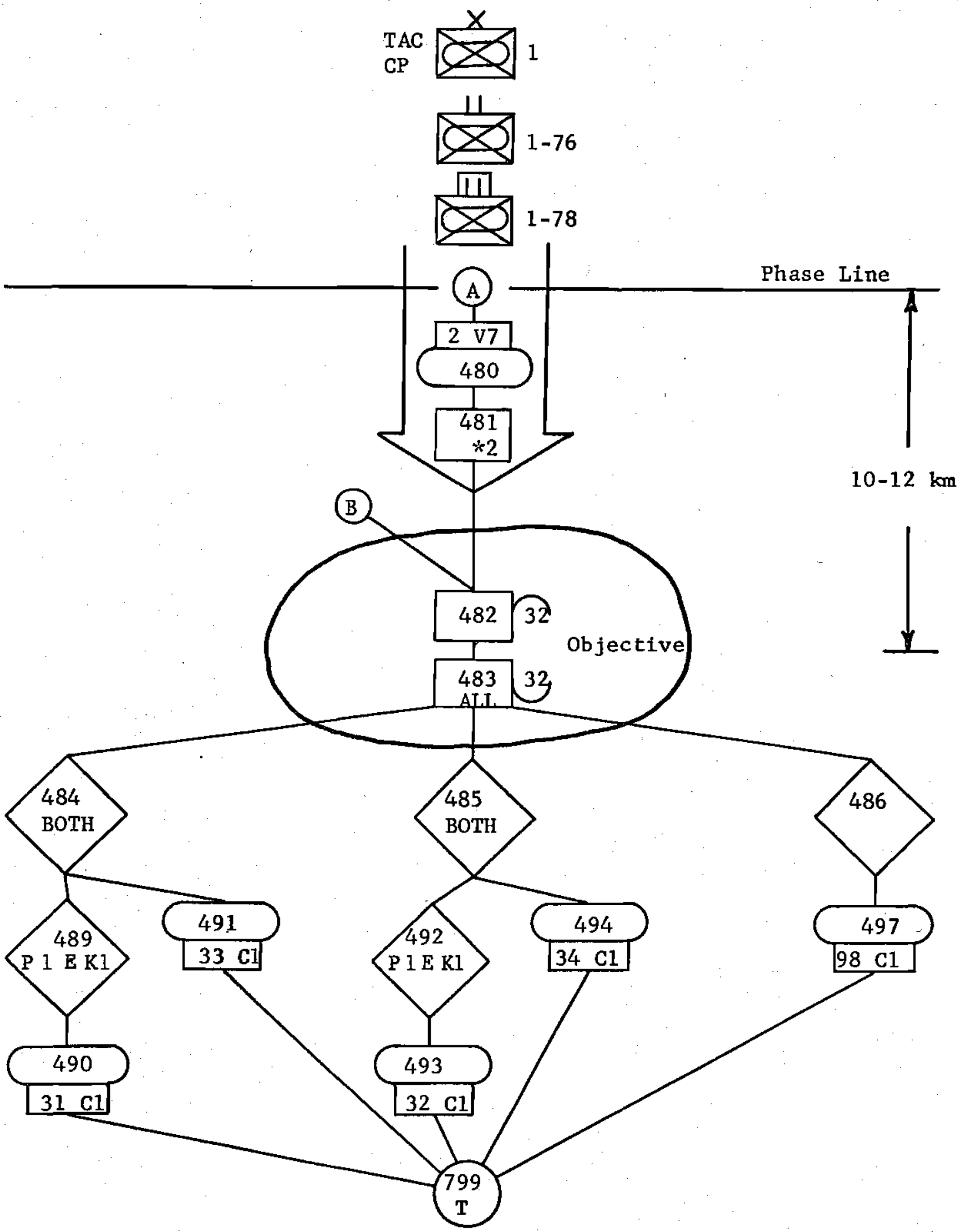

Figure 18. Concluded

in parameter 4) into a uniformly distributed distance of 4-7 km. The value of this distance is determined by function 1 (Figure 19).

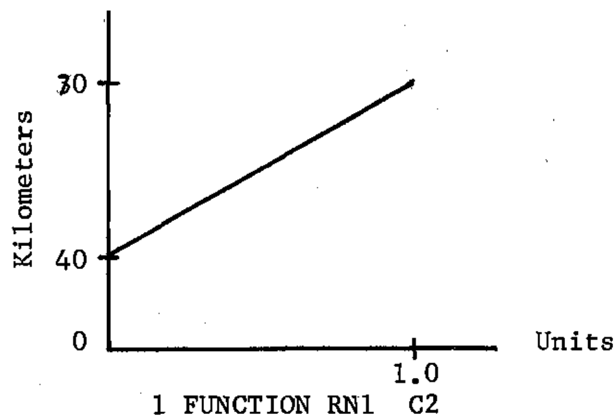

Figure 19. GPSS II Phase Line Transit Time Function

Transactions are delayed by ADVANCE block 471 for the appropriate transit time and leave the CAFB upon entering block 472, LEAVE storage 16, the CAFB. As vehicles enter the phase line, simulated by ENTER storage 31, block 473, the BOTH selection mode directs the transactions to their respective SAVEX cell locations. Transactions leave the phase line as they enter block 477, LEAVE storage 31.

Vehicle flow from the phase line to the objective area is similarly simulated by blocks 480-483. The closure times for each unit's amphibious and nonamphibious vehicles are placed in the SAVEX blocks. All transactions are terminated as they pass through the objective area and enter the TERMINATE block 799.

Southern Nonamphibious Vehicle Flow

The southern nonamphibious vehicle flow (Figure 20) is similar to that of the submodel. However, two significant differences exist. The base model simulates more than one tactical unit and the QUEUE blocks representing the C4 and C2-C3 vehicle dispersal areas have been replaced by LINK blocks 282 and 317.

As vehicles enter the DANB (Fig. 20) they are identified as either C4 or C2-C3 and are routed to their respective subareas within the dispersal area. C4 vehicles are sent to block 292, LINK chain 9. C2 and C3 vehicles are sent to LINK chain 13, block 317. The LINK blocks increase the efficiency of the computer simulation by deactivating the transactions on the user chains. As transactions enter the LINK block, they either pass through the block onto a subsequent block, determined by the ALL selection mode; or, if delayed, enter user chain 9 or 13. The system variable PR1 establishes the transaction priorities on a first come within priority group basis on each chain.

Vehicles enter the area between the DANB and the river crossing equipment sites via blocks 283-288, ENTER storages 43-48. The number of vehicles permitted in this area is controlled by the capacity limit of each storage. The first vehicles to arrive at the DANB move directly to these blocks until the capacity limits have been filled. Once full, subsequent vehicles are refused entry into the area and must wait in the DANB. This is simulated by the user chains. Blocks 252, 297, and 298 act as traffic control posts which prohibit premature vehicle entry into the crossing sites. Transactions are delayed until they can move directly to a crossing site.

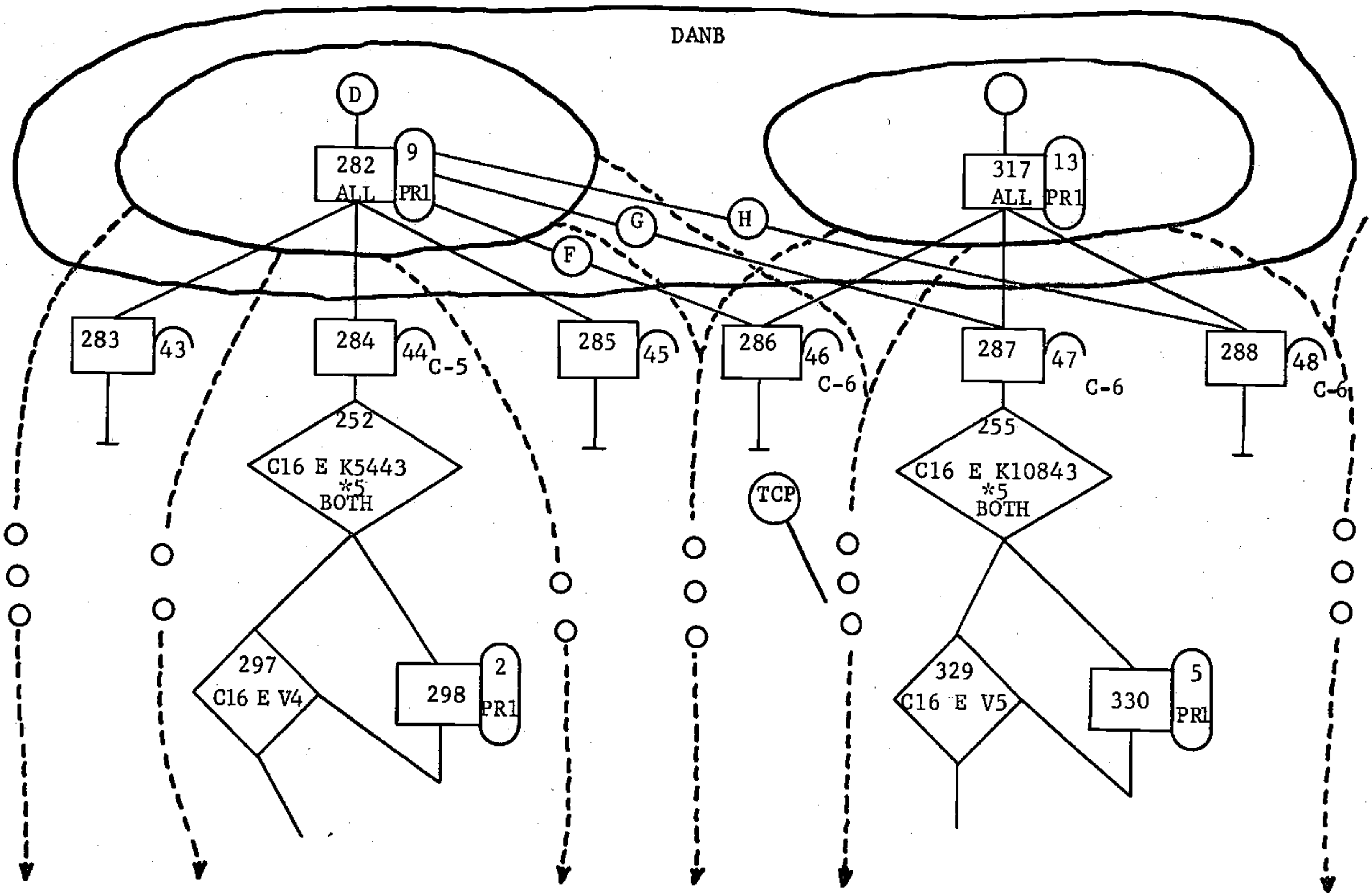

Figure 20. Southern Nonamphibious Vehicle Flow

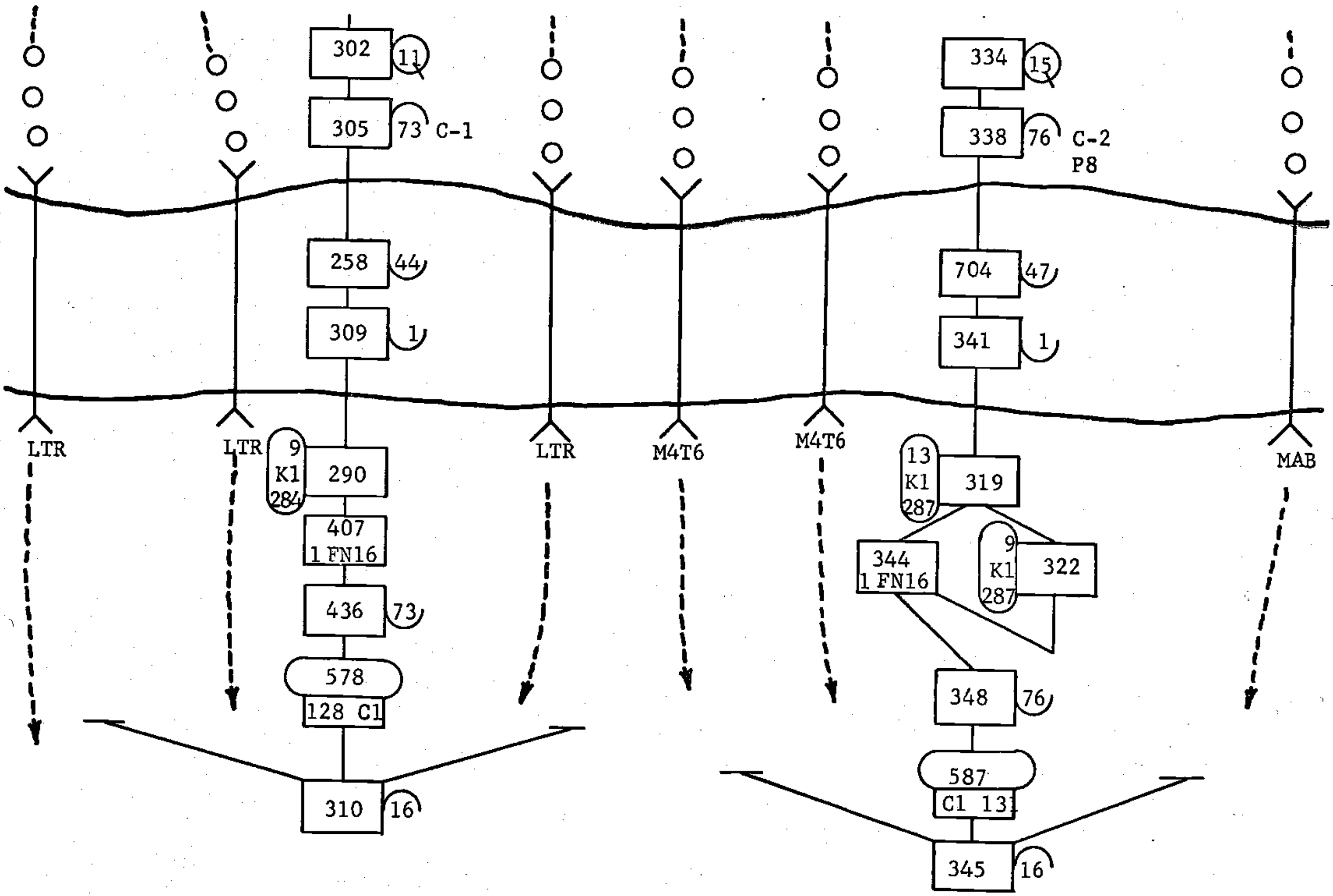

Figure 20. Concluded

The opening times for the LTR's, M4T6's, and MAB's are simulated by variables 4, 5, and 6, respectively.

Table 5. Southern River Crossing Equipment Opening Times

Equipment	Opening Time	Equivalent Computer Statement (Variable Statement)
LTR	K+1.0 hr	4 Variable X9+K3600
M4T6	K+2.5 hrs	5 Variable X9+K9000
MAB	K+1.2 hrs	6 Variable X9+K4320

K is the time the northern and southern engineers complete their river bank reconnaissance. The reconnaissance is simulated by the engineer portion of the Special Unit Processing Section (Appendix D). The opening times are stored in SAVEX cell 9 for the southern section and 11 for the northern section of the base model.

The flow of vehicles from the river crossing equipment queues to the far bank is also similar to the submodel flow. As a transaction enters an UNLINK block, for example block 290, the specification in the block indicates that one transaction is to be released from user chain 9, block 292, and sent to block 284. However, because all vehicles use the M4T6's and MAB's, an additional UNLINK block is required for this section. As a transaction leaves the CANB, block 341, it enters block 319, UNLINK 13. If transactions are waiting on this chain (the C2-C3 vehicle dispersal subarea), one transaction is sent to block 287 from the chain and the original transaction is directed to block 344. Block 344 simulates the river crossing delay. If no transactions are on user chain 13, the original transaction is sent to block 322, UNLINK 9. Thus, having no transactions available on chain 13, the original transaction attempts to release a transaction from user chain 9 (the C4 vehicle dispersal subarea). After accomplishing this, the original transaction moves to block 344. This sequence insures that the heavier vehicles, the C2 and C3 vehicles, receive priority for the M4T6 and MAB river crossing equipment.

The only difference between the M4T6 and MAB flows is the capacity value of the ENTER blocks which represent the M4T6's and MAB. The M4T6 capacity is two; the MAB capacity is four. The capacities are placed in each transaction's parameter 8 by ASSIGN blocks as the transactions are identified as either C2, C3, or C4 vehicles.

After crossing the river, all transactions flow through SAVEX blocks which store their time of entry, and then enter either block 310 or 345, ENTER 16, the CAFB. River crossing equipment usage times are computed by the Statistics Gathering Section by variable statements which subtract the equipment opening time from last transaction entry time contained in the appropriate SAVEX cell. For example, the total usage time of the LTR simulated by ENTER storage 73 is obtained by subtracting the opening time of the LTR (the value of variable 4) from the time the last vehicle clears the LTR (the value in SAVEX cell 128, block 578).

Far Bank Nonamphibious Vehicle Flow

As the nonamphibious vehicles depart the rafts and enter the CAFB (Figure 21), they move directly to the Departure Area South Far Bank (DASFB); to the Holding Area South Far Bank (HASFB); and finally, to the objective area.

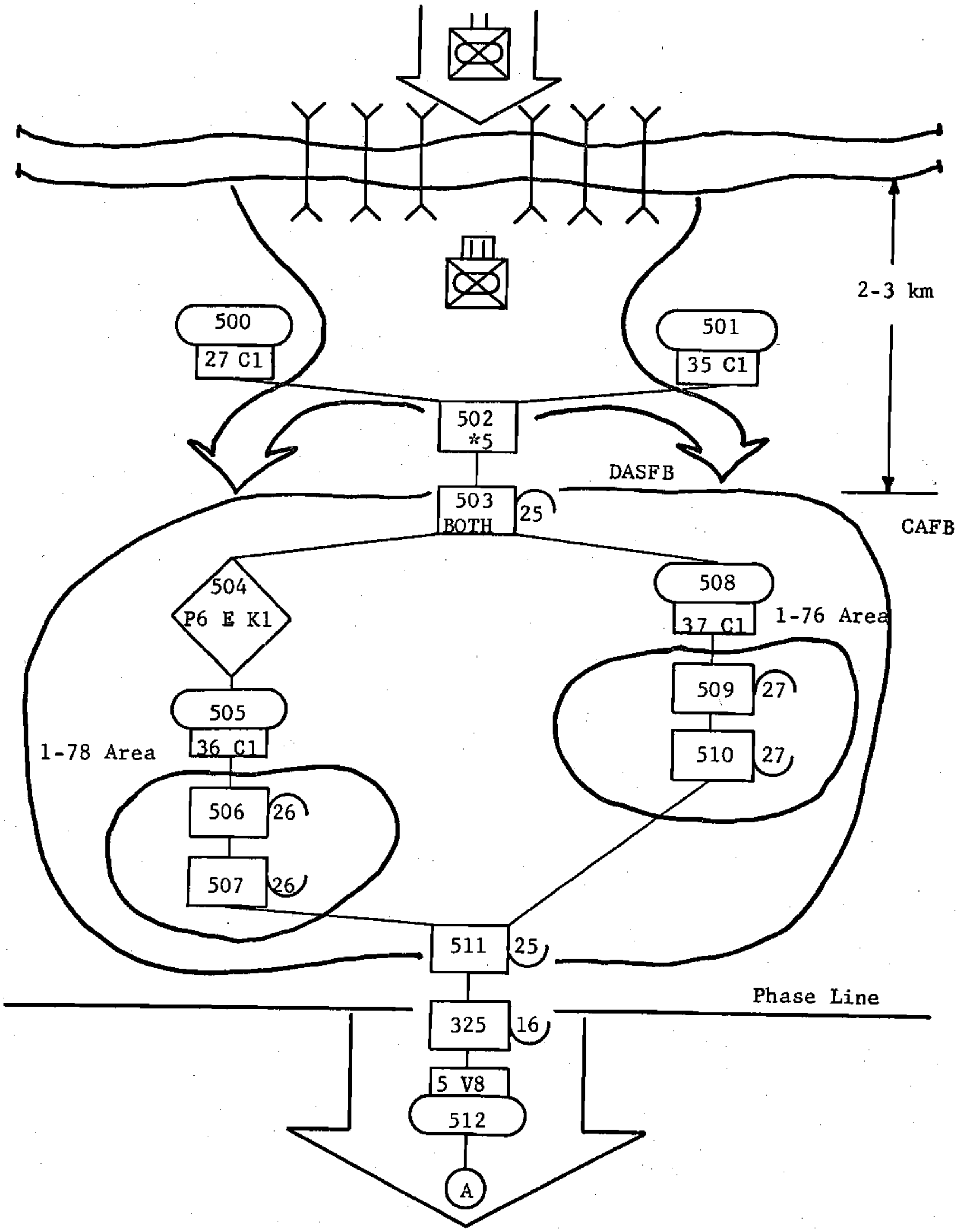

Figure 21. Southern Nonamphibious Vehicle Flow, CAFB

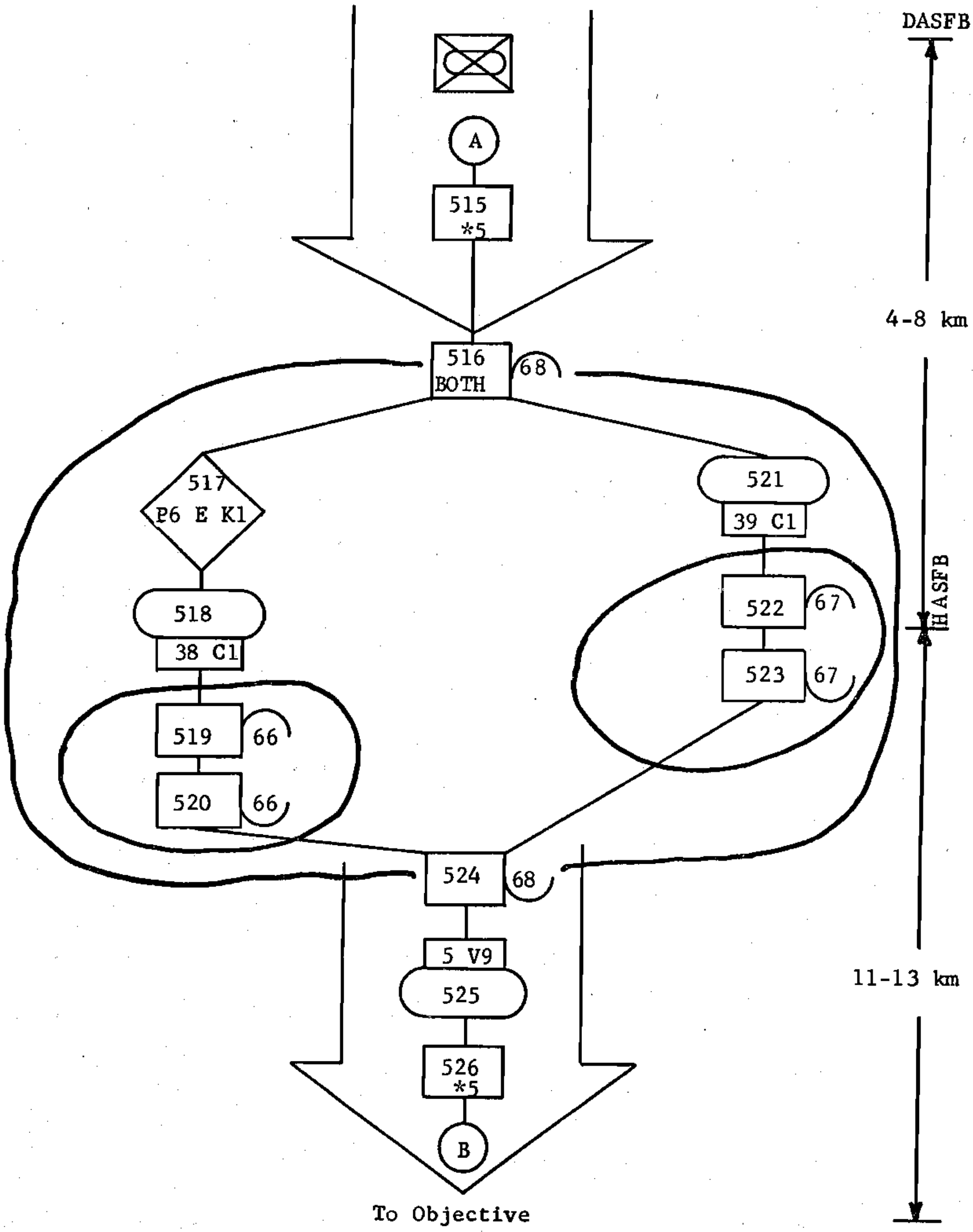

Figure 21. Concluded

SAVEX blocks 500 and 501 store the closing times of U1 and U2 in the CAFB and direct these units' transactions to ADVANCE block 502. This block delays each transaction for a simulated transit time equivalent to traveling 2-3 km at a 7 kph rate of movement. The transit time is effected by indirect specification to the value of each transaction's parameter 5, a value previously computed and placed in this location by ASSIGN blocks.

Upon entering the DASFB, simulated by ENTER storage 25, block 503, transactions proceed to their respective unit subareas. U1 transactions move to ENTER storage 26; U2's move to block 509, ENTER storage 27. SAVEX blocks 505 and 508 maintain the closing times of each unit. Both units depart the DASFB via block 511, LEAVE storage 25. Leaving the CAFB is simulated as transactions enter LEAVE storage 16, the CAFB. The value of variable 8, which represents the DASFB-HASFB transit time, is assigned to each transaction's parameter 5. This delay is also simulated by indirect specification to the value contained in parameter 5. The variable statement from which the delay is computed represents a uniformly distributed distance (4-8 km) divided by the rate of movement (7 kph). The distance range, as all others, is the minimum and maximum limit as measured from the CGSC problem topographical map.

After the transit time delay, vehicles enter the HASFB, ENTER storage 68, and are routed by the BOTH selection mode to their respective unit subareas, ENTER storage 66 and 67. As in the DASFB, the closing times of the units are stored in appropriate SAVEX cells. Transactions leave the HASFB as they enter block 524, LEAVE storage 68. Transit times are assigned by ASSIGN block 525 to simulate the 11-13 km distance from the HASFB to the objective. The delay is simulated by ADVANCE block 526, from which the transactions enter block 482, ENTER storage 32, the objective (Fig. 18).

CHAPTER IV

EXPERIMENTATION

General

The experimental phase of this research was conducted in two stages. Initially, a series of computer runs was conducted to verify the base model logic and to compare the results to the data contained in the CGSC problem. Subsequent runs were made for seven base model configurations to examine the effect of the tactical formation and river crossing equipment availability on selected variables.

Initial Validation Runs

Approximately 100 computer runs were conducted during the verification and validation stage. The base model was structured in a manner analogous to the military symbology which can be used to visually portray a river crossing operation. Many parameters are available for manipulation; however, it is believed that the values selected are realiztic and reflect the most accurate data available to the author from U. S. Army publications (30, 10, 9, 29, and 32). It is noted, moreover, that these data do not purport to imply a level of accuracy which could be obtained from empirical data gathered from actual river crossing field exercises.

Table 6 contains the base model results as they compare to selected critical variables from the CGSC problem.

Table 6. Comparison of Means (Hours)

River Crossing Equipment Type	Mean Equipment Usage Base Model	CGSC Problem	Percent Difference
LTR	7.830	6.660	+ 17.5
M4T6	6.312	6.250	+ 0.19
MAB	7.239	5.300	+ 36.5
Bridge	1.180	1.200	- 1.66

Ten runs, using different random number seeds, of the base model were conducted and the 95 percent confidence intervals for the means were computed.

Table 7. Ninety-five Percent Confidence Intervals for Selected Sample Means

Variable	Mean (Hours)
LTR	7.88 ± 0.064
M4T6	6.37 ± 0.025
MAB	7.31 ± 0.073

Initial Discussion of Results

The results contained in Table 6 indicate the model's results as compared to the CGSC problem. The 36.5 percent difference in the MAB usage mean is believed to be caused by an underlying assumption used to compute the CGSC usage mean. This assumption is that the MAB ferries operate at 100 percent capacity. The base model structure is such that the resulting MAB simulation indicates an 87-94 percent operating capacity, which appears to be more realistic when one considers that the capacity of the MAB permits all nonamphibious vehicles entry. The random nature of type vehicle arrivals indicates that all crossings will not be made at maximum capacity. Another factor causing these differences is the assumed routing of vehicles to each river crossing site. The base model simulates a routing such that vehicles use the crossing sites in their respective unit zone of action. The bridge was used by units which could logically arrive in the CANB at a time equal to or greater than the opening time.

A final significant factor which has probably affected the verification results is the parameter values assigned to the base model. Numerous parameters such as queue limitations, river ingress and egress times, uniformly distributed transit times, etc., have been incorporated into the simulation model to provide the user a realistic, flexible analytical tool. The methodology demonstrated by the CGSC problem does not consider these parameters.

Experimental Runs

Seven tactical formation and river crossing equipment combinations were simulated to examine their effects on selected variables. Each experiment is identified by a letter-digit code. The letter designates the type of tactical formation; the digit, the river crossing equipment availability (see Table 8).

Table 8. Experimental Runs

Formation	River Crossing Crossing Equipment Capability			
	Equipment Status			
	1	2	3	4
A	7 LTR 4 M4T6 2 MAB 1 Bridge	5 LTR 4 M4T6 2 MAB 1 Bridge	7 LTR 2 M4T6 2 MAB 1 Bridge	7 LTR 4 M4T6 1 MAB 1 Bridge
B	7 LTR 4 M4T6 2 MAB 1 Bridge	5 LTR 4 M4T6 2 MAB 1 Bridge	7 LTR 2 M4T6 2 MAB 1 Bridge	

Formation A is the base model tactical configuration, Fig. 15. Formation B is a variation of this configuration which decreases the Formation frontage. Instead of advancing on a wide front with four battalions of the assault echelon on line, Formation B is a narrower formation which uses a two-up, two-back formation. The assault battalions are deployed in a box-like shape; two forward, followed by two in the rear. Formation B, therefore, narrows the brigade front and increases the brigade depth.

River Crossing Time

The river crossing time is determined by the maximum river crossing equipment usage mean. In all experiments, the LTR's realized this value. This is predictable when one considers that approximately 73 percent of the nonamphibious vehicles in the brigade task organization are C4 type vehicles. The crossing time is determined by subtracting the time the last vehicle clears a particular raft or ferry from the time that equipment opened. It does not include the Line of Departure to crossing site transit time or the time required for engineer reconnaissance.

Table 9. River Crossing Time (Hours)

Formation	Equipment Status			
	1	2	3	4
A	7.830	8.753 (+ 12%)	8.910 (+ 14%)	8.607 (+ 10%)
B	7.982 (+ 2%)	8.700 (11%)	8.997 (+ 15%)	

The most significant increase in river crossing time was caused by the loss of two, M4T6 rafts. These rafts accommodate all nonamphibious vehicles and are distributed equally between the two main crossing areas within the brigade zone. The type of formation did not appear to influence the crossing time in any equipment allocation.

Crossing Area Vehicle Density

The crossing area, the total area bounded by the CANB and CAFB, is an area especially critical to successful river crossing operations. The area contains all river crossing equipment and, therefore, offers the enemy a very lucrative nuclear target. Disregarding the critical nature of the equipment, one must still consider that the nature of the area is such that vehicles tend to cluster and accumulate in it. The vehicle density, therefore, must be minimized in order to avoid offering the enemy a lucrative nuclear target.

Table 10. Crossing Area Vehicle Density

Formation	Equipment Status							
	1		2		3		4	
	CANB	CAFB	CANB	CAFB	CANB	CAFB	CANB	CAFB
A	660	180	693 (+ 5%)	186 (+ 3%)	691 (+ 5%)	187 (+ 4%)	776 (+ 17%)	228 (+ 27%)
B	659 (< 1%)	181 (< 1%)	684 (+ 4%)	186 (+ 3%)	684 (+ 4%)	185 (+ 3%)	--	--

As expected, the CANB density is far greater than the CAFB density. The formation did not appear to influence the density. However, the loss of the MAB did significantly increase both the CANB and CAFB vehicle density.

Mean Crossing Area Transit Time

The transit time through the CANB is the time required for a vehicle, either amphibious or nonamphibious, to move from the Line of Departure to the river. The CAFB transit time is the time required for a vehicle to move from the far bank to the Phase Line or Traffic-Regulating Line used to delineate the CAFB boundary. This transit time is an indicator of a force's potential nuclear vulnerability.

Table 11. Mean Crossing Area Transit Times (Hours)

Formation	Equipment Status 1		2		3		4	
	CANB	CAFB	CANB	CAFB	CANB	CAFB	CANB	CAFB
A	4.080	1.300	4.293 (+ 5%)	1.345 (+ 3%)	4.278 (+ 5%)	1.356 (+ 4%)	4.806 (+ 18%)	1.652 (+ 27%)
B	4.050 (< 1%)	1.290 (< 1%)	4.236 (+ 4%)	1.344 (+ 3%)	4.240 (+ 4%)	1.345 (+ 3%)	--	--

As found in the previous results, the time required to cross the CANB is significantly greater than that required to move through the CAFB. The formation, again, did not appear to influence this variable. However, the loss of the MAB did result in a significant increase in CANB and CAFB transit times.

Near Bank Dispersal Area Delays

Ideally, a crossing force moves without delay across the Line of Departure, through the CANB, across the river, and onto the objective area. Holding areas and dispersal areas are designated, however, to provide temporary assembly areas for vehicles outside of and within the crossing area as previously indicated in Fig. 1. The base model is structured so that it simulates a force which utilizes these areas. All combat, combat support, and combat service support vehicles move with their respective tactical units and, if delayed in transit, queue in either the C4, or C2-C3 subareas within the DANB. Vehicles are assigned a movement priority and are directed onto the rafts and ferries as they become available. Thus, another variable related to a force's potential nuclear vulnerability is the delay time in the DANB.

Table 12. Nonamphibious Vehicle Mean Time Delay in Dispersal Areas Near Bank (Hours)

Formation	Equipment Status							
	1		2		3		4	
	C4	C2-C3	C4	C2-C3	C4	C2-C3	C4	C2-C3
A	5.060	3.940	6.032	3.958	5.481	4.570	5.235	5.450
			(+ 19%)	(< 1%)	(+ 8%)	(+ 16%)	(+ 3%)	(+ 38%)
B	5.050	3.810	5.320	3.790	5.380	4.421	--	--
	(< 1%)	(- 3%)	(+ 5%)	(- 4%)	(+ 6%)	(+ 12%)		

Formations A and B do not differ significantly in their influence on the mean nonamphibious vehicle delay in the DANB. C2-C3 vehicles are delayed less than C4 vehicles in all experiments except A4, the loss of the MAB. This loss significantly increased the C2-C3 delay. The loss of two LTR's, experiment A2, indicated the most significant increase in the C4 vehicle subarea. The minimum time in the DANB was achieved by the equipment status 1, the maximum allocation.

Discussion of Results

The variation in tactical formation produced no significant change in the variables studied. Prior to conducting the final experimental runs, a test run was made which simulated the B1 experimental configuration. The formation was changed to reflect the data contained in (30) and the resulting four battalion assault echelon force was structured to occupy an area two kilometers wide by two kilometers deep. Each battalion occupied on square kilometer and its vehicles were assumed to be uniformly distributed throughout the area. This configuration produced very little change in the data resulting from the A1 run. In an effort to determine whether or not the model was responsive to a formation variation, the depth of the four battalion assault echelon formation was increased by delaying rear battalions so that a 500 meter separation existed between them and the two lead battalions. This formation did yield results which indicated that the model was responsive to the change and the run was designated the B1 experiment. It would appear that increased depths will yield valid results. However, the direct relationship between the formation depth and the variables of interest requires further experimentation.

The variations of equipment allocations indicate that the MAB was the most critical piece of river crossing equipment. Although the loss of two M4T6's, experiment A2 and B2, did cause the longest mean crossing time, the potential nuclear vulnerability of the crossing force, as measured by the three variables, Figs. 10, 11, 12, was influenced most significantly by the loss of the MAB.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

General Comments

The base model is a GPSS II simulation model of one specific river crossing operation plan. All model parameters were determined from those applicable to the plan. The model may be adapted to simulate many different plans which involve varying terrain conditions, varying day and night movement conditions, varying crossing area depths and widths, and varying river crossing equipment allocations by assigning the proper values to the model parameters. As was previously pointed out, the results are predicated on the input data accuracy. It must be noted that the model interarrival times, distribution, and other parameter values are not based on empirical, observed data, but on data contained in the references previously cited which are taken from unclassified military sources.

Conclusions

1. The base model structure and logic, when expressed in a GPSS II flow diagram, afford a potential user an easily understandable symbology very analogous to the military symbology familiar to staff officers and service school students and instructors studying river crossing operations.

2. The base model provides the potential user an analytical tool

with which one may collect and evaluate quantitative data on selected critical variables and evaluate the interactions of these variables with regard to their effect on the river crossing plan options.

3. In addition to being an analytical aid to the military student and instructor, the base model provides a means by which current river crossing equipment operational capabilities, river crossing planning methodologies, and the data input used to determine the optimum equipment allocations may be quantitatively analyzed and validated by empirical data gathered from field tests and exercises.

4. The results obtained from the experimental runs indicate that the variable which most significantly influences a force's river crossing time and potential vulnerability to mass destruction weapons is the capability of the river crossing equipment allocated to the force.

5. Varying the four battalion assault echelon formation from a wide, on-line formation to one which is 50 percent narrower and 150 percent deeper does not significantly affect the crossing force vehicle density within the crossing area.

6. The loss of heavy river crossing equipment, either the M4T6 rafts or the MAB ferries, adversely affects a force's river crossing time more than the loss of light equipment such as LTR's, despite the fact that only approximately 27 percent of the nonamphibious vehicles require the heavy equipment. The loss of one MAB, moreover, appears to have the most adverse effect on the variables indicating potential nuclear vulnerability. Thus, of the three types of rafting and ferrying equipment allocated to the base model crossing force, the MAB seems to be the most critical.

Recommendations

1. Further study of the model structure developed in this study should be conducted to determine modifications which will decrease the computer run time while maintaining the present number of variables and parameters available for analysis.

2. Should empirical data become available for input to the model, sufficient replications of experimental runs should be conducted to provide a statistical basis for more exhaustive analysis of the data currently used for determining river crossing plan options.

3. Further experiments should be conducted to determine the "optimum" tactical formation with regard to achieving desirable levels of vehicle densities and delays within the river crossing area. A critical question is whether or not this "optimum" formation would provide mutual support among subunits.

4. In that the division is the smallest unit possessing organic river crossing equipment, it is recommended that, concomitant with the above recommendations, the base model be enlarged to simulate this force size operation.

5. A simulation model is very inexpensive to use when compared to actual maneuvers involving river crossing operations. It is, therefore, an appealing research tool. Empirical data from various small unit river crossing operations could be gathered, synthesized, and used to validate the larger unit base model. This tactic recognizes the financial limitations which hinder the gathering of empirical data from large unit river crossing operations and would enhance the appealing nature of the simulation model by increasing the model validity and accuracy.

APPENDICES

APPENDIX A

RIVER CROSSING EQUIPMENT CHARACTERISTICS

General

The division's organic river crossing equipment is contained in the division engineer battalion's bridge company. The bridge company consists of a headquarters, an armored vehicle launched bridge (AVLB) platoon, and either two heavy raft platoons equipped with Mobile Assault Bridges (MAB's) or two bridge platoons equipped with M4T6 or class 60 bridging. In addition to the MAB, M4T6, or class 60 bridging, the bridge company provides reconnaissance boats and Light Tactical Rafts (LTR's) to support river crossing operations.

Mobile Assault Bridge

The MAB consists of individual amphibious vehicles which, when joined together, form a class 60 bridge. Each vehicle can move on roads up to speeds of 55 kph and in the water at speeds up to 11 kph. The floor of the bridge is mounted on top of and parallel to the long axis of the vehicle. The floor is turned perpendicular to the long axis of the vehicle to form the bridge. When equipped with MAB's, the bridge company has the capability to construct one 144 meter bridge; two 80 meter bridges; or four 48 meter self-propelled ferries (30).

M4T6 Bridging

The M4T6 bridging is a combination of M4 and class 60 equipment. The superstructure of the bridge is M4 equipment and the rubber pneumatic floats come from the class 60. Unlike the MAB, the M4T6 is not self propelled. The bridge must be carried in sections by prime movers to the crossing site, assembled, and placed into the water. When used as rafts, the M4T6 is propelled by power boats. The M4T6 can be used as one 170 meter class 50 float bridge, or eight class 50 rafts (30).

Light Tactical Rafts

Two sets of LTR's are allocated to each divisional engineer battalion. Like the M4T6, the LTR must be transported by prime movers to the crossing sites and requires an external source of power when used as rafts. Each LTR set may be used as one 4-pontoon raft, or one 44 foot class 12 bridge (30).

Armored Vehicle Launched Bridge

The AVLB is used to quickly span short gaps less than 60 feet in width. The bridge is hinged in the middle of its span and is mounted on top of a tank chassis. When employed, the bridge unfolds--sissors-like--onto the gap. The bridge can be launched in less than two minutes and can be retrieved from either end in less than ten minutes. The maximum crossing capacity is 75 tons (30).

APPENDIX B

BRIGADE AND BASE MODEL TASK ORGANIZATIONS

Table 13. Brigade Task Organization and Vehicle Types

Unit	Vehicle Types			
	C1	C4	C2-C3	
Bde HQ	13	32	1	
1-76 Mech Inf	83	68	20	
1-77 Mech Inf	83	68	20	
1-78 Mech Inf	83	68	20	
1-4 Arm	33	67	83	
1-23 Cav	117	77	28	
63d Arty Gp HQ	0	41	0	
1-40 Arty (155, SP)	46	92	33	
1-651 Arty (155, towed)	0	86	41	
1-652 Arty (155, towed)	0	86	41	
A/1-441 Arty (Vulcan)	19	46	4	
A/52d Engr	10	12	7	
D/52d Engr	10	12	7	
AVLB Sec	0	0	3	
Hv Raft Plat	12	7	0	
Fwd Comd Tml Tm	0	4	0	
MP Plat	0	10	0	
Fwd Spt Co	0	30	2	
Med Co	0	27	0	
Fwd Sup Sec	0	2	0	
TOTAL	509	835	310	= 1634 Vehicles
Corps/Army Engineers*				274 Vehicles
GRAND TOTAL				1938 Vehicles

*The Corps and Army Engineer vehicles remain in the near bank and far bank engineer parks and contribute to the cross-area vehicle densities.

Table 14. Base Model Task Organization

ASSAULT ECHELON			
NORTHERN AREA	TOTAL VEHICLES	SOUTHERN AREA	TOTAL VEHICLES
TF 1-77 Mech Inf*	266	TF 1-78 Mech Inf*	266
A/1-4 Arm		B/1-4 Arm	
Plat/A/52 Engr		Plat/A/52 Engr	
1-40 Arty (-)		1-40 Arty	
1-23 Cav*	212	1-76 Mech Inf (-)*	156
Plat/1-441 Arty*	7	Plat/A/52 Engr	
		A/1-441 Arty (-)*	58
		Bde TAC CP*	8

ENGINEER ECHELON			
NORTHERN AREA	TOTAL VEHICLES	SOUTHERN AREA	TOTAL VEHICLES
Nothern Engineers*	164	Southern Engineers*	156
61 Engr Gp		61 Engr Gp (-)	
D/52 Engr		D/52 Engr	
AVLB Sec		AVLB Sec	
Hvy Raft		Hvy Raft	

RESERVE	
UNIT	TOTAL VEHICLES
1-4 Arm*	135
FIRE SUPPORT ECHELON	
UNIT	TOTAL VEHICLES
1-651 Arty*	102
1-652 Arty*	102
FOLLOW-UP AND REAR ECHELONS	
UNIT	TOTAL VEHICLES
Unit trains and combat service support elements from all units	306
TOTAL VEHICLES ENTERING BRIGADE AREA	1938

*Indicates unit generator for unit with asterisk and all immediately below.

APPENDIX C

BASE MODEL COMPUTER LISTING

	JOB	161507247501	
1	CAPACITY	1938	TOT VEH EN CANB INCL 299 ENGR VEH AND 1639 VEH ATCH BDE
2	CAPACITY	15	CS7NB
3	CAPACITY	15	CS6NB
4	CAPACITY	15	CS5NB
5	CAPACITY	15	CS7FB
6	CAPACITY	15	CS6FB
7	CAPACITY	15	CS5FB
8	CAPACITY	15	CS4NB
9	CAPACITY	15	CS3NB
10	CAPACITY	15	CS2NB
11	CAPACITY	15	CS4FB
12	CAPACITY	15	CS3FB
13	CAPACITY	15	CS2FB
14	CAPACITY	7	AAA PLAT SECURITY POSN VIC CSS
15	CAPACITY	58	AAA BTRY(-) POSN VIC CSN
16	CAPACITY	1938	CAFB
17	CAPACITY	11	ENGR PK FBS
18	CAPACITY	145	ENGR PK NBS
19	CAPACITY	11	ENGR PK FBN
20	CAPACITY	153	ENGR PK NBN
21	CAPACITY	2	MAB 2
22	CAPACITY	2	MAB 2
23	CAPACITY	2	MAB 1
24	CAPACITY	2	MAB 1
25	CAPACITY	257	DASFB
26	CAPACITY	157	U1AREA DASFB
27	CAPACITY	88	U2AREA DASFB
29	CAPACITY	109	U1 ALIGN AREA
30	CAPACITY	68	U2 ALIGN AREA
31	CAPACITY	185	U1U2U6 C1 ARR PL
32	CAPACITY	450	U1U2U6 ARR OBJ
33	CAPACITY	109	U3 ALIGN AREA
34	CAPACITY	117	U5 ALIGN AREA
35	CAPACITY	226	U3U5 ARR PL
36	CAPACITY	478	U3U5 OBJ
37	CAPACITY	252	DANFB
38	CAPACITY	157.	U3AREA DANFB
39	CAPACITY	95	U5AREA DANFB
40	CAPACITY	252	HANFB
41	CAPACITY	157	U3AREA HANFB
42	CAPACITY	95	U5AREA HANFB
43	CAPACITY	5	
44	CAPACITY	5	
45	CAPACITY	5	
46	CAPACITY	6	
47	CAPACITY	6	
48	CAPACITY	6	
49	CAPACITY	35	SFS AREA U4C1C2
50	CAPACITY	25	U4 ALIGN S
51	CAPACITY	135	U4 ASMBY AREA
53	CAPACITY	5	LTR4
54	CAPACITY	5	LTR 3

55	CAPACITY	5	LTR 2
56	CAPACITY	5	LTR 1
57	CAPACITY	6	
58	CAPACITY	6	
59	CAPACITY	6	
60	CAPACITY	8	U6 ALIGN
61	CAPACITY	12	U6AREA DASFB
62	CAPACITY	12	U6AREA HASFB
63	CAPACITY	7	BRIDGE
64	CAPACITY	204	U11U12 FPFB
65	CAPACITY	102	U12 FP VIC LD
66	CAPACITY	200	
67	CAPACITY	100	
68	CAPACITY	450	
70	CAPACITY	34	NFS AREA U4C1C2
71	CAPACITY	24	U4 ALIGN N
72	CAPACITY	1	
73	CAPACITY	1	
74	CAPACITY	1	
75	CAPACITY	2	
76	CAPACITY	2	
77	CAPACITY	4	
80	CAPACITY	1	
81	CAPACITY	1	
82	CAPACITY	1	
83	CAPACITY	1	
84	CAPACITY	2	
85	CAPACITY	2	
86	CAPACITY	4	
1	VARIABLE	FN1*K3600/P4/K10	TT LD-CSNB TT CSFB-PL 4-7KM
2	VARIABLE	FN2*K3600/FN3/K100	TT RIVER(100-175M)/(3-5KPH)
3	VARIABLE	FN5*K3600/P4/K10	TT LD-DA TT DA-CS 2-3KM
4	VARIABLE	X9+K3600	LTR OPEN K+1 S
5	VARIABLE	X9+K9000	M4T6 OPEN K+2.5 S
6	VARIABLE	X9+K4320	MAB OPEN K+1.2
7	VARIABLE	FN4*K3600/P4/K10	TT PL-OBJ N
8	VARIABLE	FN6*K3600/P4/K10	TT DASFB-HASFB 4-6KM
9	VARIABLE	FN7*K3600/P4/K10	TT HASFB-OBJ 11-13KM
10	VARIABLE	FN8*K3600/P4/K10	TT RIV-PL N 5.5-6.5KM
11	VARIABLE	FN9*K3600/P4/K10	TT PL-OBJ N 9-12KM
12	VARIABLE	FN12*K3600/P4/K10	TT 1-4ARM AA-OBJ 17-19KM
13	VARIABLE	X11+K3600	LTR N OPEN K+1
14	VARIABLE	X11+K9000	M4T6 N OPEN K+2.5
15	VARIABLE	X11+K4320	MAB N OPEN K+1.2
16	VARIABLE	X11+K23400	BRIDGE OPEN K+6.5
17	VARIABLE	FN15*K3600/P4/K10	TT RIV-PL N TRNS 7-8KM
18	VARIABLE	X11+K21240	
19	VARIABLE	N654+N693	
20	VARIABLE	X120-V13	
21	VARIABLE	X121-V13	
22	VARIABLE	X122-V13	
23	VARIABLE	X123-V13	
24	VARIABLE	X124-V14	
25	VARIABLE	X125-V14	
26	VARIABLE	X126-V15	
27	VARIABLE	X127-V4	
28	VARIABLE	X128-V4	

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 29   VARIABLE     X129-V4
 30   VARIABLE     X130-V5
 31   VARIABLE     X131-V5
 32   VARIABLE     X132-V6
 33   VARIABLE     X104-X103
  1   FUNCTION     RN1    C2      D LD-RIV 4-7KM
0     40     1.0   70
  2   FUNCTION     RN1    C2      RIV WIDTH 100-175M
0     100    1.0   175
  3   FUNCTION     RN1    C2      C1 AMPHIB VEL 3-5KPH
0     30     1.0   50
  4   FUNCTION     RN1    C2      D PL-OBJ 10-12KM
0     100    1.0   120
  5   FUNCTION     RN1    C2      D LD-DA DA-CSNB 2-3KM
0     20     1.0   30
  6   FUNCTION     RN1    C2      D DASFB-HASFB 4-6KM
0     40     1.0   60
  7   FUNCTION     RN1    C2      D HASFB-OBJ 11-13KM
0     110    1.0   130
  8   FUNCTION     RN1    C2      D RIV-PL N 5.5-6.5KM
0     55     1.0   65
  9   FUNCTION     RN1    C2      D PL-OBJ N 9-12KM
0     90     1.0   120
 10   FUNCTION     P6     D4      ASGN U1C2PR7 U2C2PR6 U4C2PR4 U6C2PR5
1.0   7.0    2.0   6.0    4.0     4.0    6.0    5.0
 11   FUNCTION     P6     D4      ASGN  U1C3C4PR3 U2C3C4PR2 U4C3C4PR0 U6C3C4PR1
1.0   3.0    2.0   2.0    4.0     0.0    6.0    1.0
 12   FUNCTION     RN1    C2      D PL-OBJ U4 17-19KM
0     17     1.0   19
 13   FUNCTION     P6     D4      ASGN  U3C2PR7 U5C2PR6 U4C2PR5 U6PR4
3.0   7.0    4.0   5.0    5.0     6.0    6.0    4.0
 14   FUNCTION     P6     D4      ASGN  U3C3C4PR3 U5C3C4PR2 U4C3C4PR0 U6C3C4 PR1
3.0   3.0    4.0   0.0    5.0     2.0    6.0    1.0
 15   FUNCTION     RN1    C2      D RIV-PL N 7-8KM
0     70     1.0   80
 16   FUNCTION     RN1    C2
0     450    1     900
 17   FUNCTION     P8     D3
5     163    6     164    7       165
 18   FUNCTION     P8     D3
11    200    12    201    13      202
 1    TABLE        MP7    820     60     14
 2    TABLE        MP7    820     60     14
 3    TABLE        IA     400     60     10
 4    TABLE        IA     200     60     15
 5    TABLE        IA     100     60     10
 6    TABLE        IA     400     60     10
 7    TABLE        IA     300     60     15
 8    TABLE        IA     100     60     10
*                         TF1-78 AND TF1-77 GENERATORS
 1    ORIGINATE    0      266                   2                3        1
 2    ASSIGN       3      K1              ALL   3         6
 3    COMPARE      N2     LE      K109          7                            P3 ASLT ECHELN
 4    COMPARE      N2     LE      K216          8                            C1 VEH 109
 5    COMPARE      N2     LE      K233          9                            C4 VEH 107
 6    ASSIGN       1      K3                    10                           C2 VEH 17
 7    ASSIGN       1      K1                    10                           C3 VEH 33
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  8   ASSIGN      1    K4                     10
  9   ASSIGN      1    K2                     10
 10   SPLIT                                   11    27
 11   ASSIGN      6    K1                     12                      U1 TF1-78
 12   ENTER       1                           13                      U1 EN CANB
 13   SAVEX       15   C1                     140                     TM U1 CL CANB
 27   ASSIGN      6    K3                     28                      U3 TF1-77
 28   ENTER       1                           29                      U3 EN CANB
 29   SAVEX       17   C1                     177                     TM U3 CL CANB
*                      1-76 GENERATOR
 15   ORIGINATE   0    156                    16          3     1
 16   ASSIGN      3    K1                     17                      P3 ASLT ECHELN
 17   ASSIGN      6    K2              ALL    18    21                U2 1-76
 18   COMPARE     N17  LE     K68             22                      C1 VEH 68
 19   COMPARE     N17  LE     K134            23                      C4 VEH 66
 20   COMPARE     N17  LE     K151            24                      C2 VEH 17
 21   ASSIGN      1    K3                     25                      C3 VEH 5
 22   ASSIGN      1    K1                     25
 23   ASSIGN      1    K4                     25
 24   ASSIGN      1    K2                     25
 25   ENTER       1                           26                      U2 EN CANB
 26   SAVEX       16   C1                     140                     TM U2 CL CANB
*                      1-23 CAV GENERATOR
 30   ORIGINATE   0    212                    31          3     1
 31   ASSIGN      3    K1                     32                      P3 ASLT ECHELN
 32   ASSIGN      6    K5              ALL    33    35                U5 1-23 CAV
 33   COMPARE     N32  LE     K117            36                      C1 VEH 117
 34   COMPARE     N32  LE     K186            37                      C4 VEH 69
 35   ASSIGN      1    K3                     38                      C3 VEH 26
 36   ASSIGN      1    K1                     38
 37   ASSIGN      1    K4                     38
 38   ENTER       1                           39                      U5 EN CANB
 39   SAVEX       18   C1                     177                     TM U5 EN CANB
*                      AAA PLATOON GENERATOR(FOLLOWS TF 1-77)
 40   GENERATE    0    7                      41          3     1
 41   COMPARE     N28  E      K266     BOTH   42    44
 42   COMPARE     N41  E      K1              43
 43   SAVEX       1    C1                     44                      LD TM AAA PLAT
 44   ADVANCE                          ALL    45    47
 45   COMPARE     N44  LE     K5              48                      C1 VEH 5
 46   COMPARE     N44  LE     K6              49                      C4 VEH 1
 47   ASSIGN      1    K3                     50                      C3 VEH 1
 48   ASSIGN      1    K1                     50
 49   ASSIGN      1    K4                     50
 50   ASSIGN      6    K7                     51                      U7 AAA
 51   ASSIGN      3    K1                     52                      P3 ASLT ECHELN
 52   ENTER       1                           53                      U7 EN CANB
 53   SAVEX       19.  C1                     115                     TM U7 CL CANB
*                      BDE TAC CP GENERATOR(FOLLOWS 1-76)
 55   GENERATE    0    8                      56          3     1
 56   COMPARE     N25  E      K156            60
 60   ASSIGN      1    K1                     62
 62   ASSIGN      3    K1                     63                      P3 ASLT ECHELN
 63   ASSIGN      6    K6                     64                      U6 BDE TAC CP
 64   ENTER       1                           65                      U6 EN CANB
 65   SAVEX       20   C1                     140                     TM U6 CL CANB
*                      AAA BTRY(-) GENERATOR(FOLLOWS TF 1-78)
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 66   GENERATE    0      58                      67              3      1
 67   COMPARE     N12    E      K266   BOTH      68      70
 68   COMPARE     N67    E      K1               69
 69   SAVEX       3      C1                      70                             LD TM AAA(-)
 70   ADVANCE                          ALL       71      73
 71   COMPARE     N70    LE     K14              74                             C1 VEH 14
 72   COMPARE     N70    LE     K55              75                             C4 VEH 41
 73   ASSIGN      1      K3                      76                             C3 VEH 3
 74   ASSIGN      1      K1                      76
 75   ASSIGN      1      K4                      76
 76   ASSIGN      3      K1                      77                             P3 ASLT ECHELN
 77   ASSIGN      6      K7                      78                             U7 AAA(-)
 78   ENTER       1                              79                             U7 EN CANB
 79   SAVEX       21     C1                      126                            TM U7 CL CANB
*                        1-4ARMOR GENERATOR(FOLLOWS BDE TAC CP)
 80   GENERATE    0      135                     81              3      1
 81   COMPARE     N64    E      K8     BOTH      82      84
 82   COMPARE     N81    E      K1               83
 83   SAVEX       5      C1                      84                             LD TM U4
 84   ASSIGN      4      K7            ALL       85      88                     P4 VEL 7KPH
 85   COMPARE     N84    LE     K49              89                             C1 VEH 49
 86   COMPARE     N84    LE     K87              90                             C4 VEH 38
 87   COMPARE     N84    LE     K107             91                             C2 VEH 20
 88   ASSIGN      1      K3                      92                             C3 VEH 28
 89   ASSIGN      1      K1                      92
 90   ASSIGN      1      K4                      92
 91   ASSIGN      1      K2                      92
 92   ASSIGN      6      K4                      93                             U4 TF1-4ARMOR
 93   ASSIGN      3      K1                      94                             P3 ASLT ECHELN
 94   ENTER       1                              95                             EN CANB
 95   SAVEX       22     C1                      625                            TM U4 CL CANB
*                        SOUTHERN ENGINEER GENERATOR(FOLLOWS AAA PLAT)
 96   GENERATE    0      156                     97              9      2
 97   COMPARE     N52    E      K7               100
 100  ASSIGN      3      K3                      101                            P3 ENGR ECHELN
 101  ASSIGN      6      K8                      102                            U8 ENGINEERS
 102  ENTER       1                              103                            EN CANB
 103  SAVEX       23     C1            BOTH      104     215                    TM U8S CL CANB
 104  COMPARE     N103   LE     K11              113
 113  ASSIGN      1      K1                      215                            11C1VEH ENGR S
*                        NORTHERN ENGINEER GENERATOR(FOLLOWS AAA BTRY(-))
 105  GENERATE    0      164                     106             9      2
 106  COMPARE     N78    E      K58              109
 109  ASSIGN      3      K3                      110                            P3 FNGR ECHELN
 110  ASSIGN      6      K8                      111                            U8 ENGINEERS
 111  ENTER       1                              112                            EN CANB
 112  SAVEX       24     C1            BOTH      114     235                    TM U8N CL CANB
 114  COMPARE     N112   LE     K11              123
 123  ASSIGN      1      K1                      235                            11C1VEH ENGR N
*                        AAA PLAT MOVES FR LD-CROSSING SITES-FIRING POSN
 115  ASSIGN      4      K7                      116                            P4 VEL 7KPH
 116  ASSIGN      5      V1                      117                            TM=4-7KM/7KPH
 117  ADVANCE                                    118             *5             TT LD-RIVER
 118  SAVEX       6      C1                      119                            TM AAAN CL RIV
 119  STORE       14                             120                            EN FIRE POSN
 120  COMPARE     N724   GE     K510             121
 121  SAVEX       91     C1                      232                            TN AAAN LV
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*                           AAA BTRY(-) MOVES FR LD-CROSSING SITES-FIRING POSN
 126  ASSIGN      4     K7                127                           P4 VEL 7KPH
 127  ASSIGN      5     V1                128                           TM=4-7KM/7KPH
 128  ADVANCE                             129            *5             TT LD-RIVER
 129  SAVEX       7     C1                130                           TM AAAS CL RIV
 130  STORE       15                      131                           EN FIRE POSN
 131  GATE        LS20                    132
 132  SAVEX       92    C1                133                           TM AAAS LV
 133  LOGIC       I20              BOTH   59     640
 59   COMPARE     P1    E     K1          122
 122  ADVANCE                      PICK   145    147
 61   ASSIGN      8     K2         ALL    743    745
 384  GENERATE    0     58                385            3      1
 385  COMPARE     N648  GE    K43         386
 386  LOGIC       I20                     800
 640  ADVANCE                      BOTH   498    499
 498  COMPARE     N640  LE    K3          61
 499  ASSIGN      8     K1         ALL    740    745
 740  ENTER       43                      301
 741  ENTER       44                      302
 742  ENTER       45                      303
 743  ENTER       46                      333
 744  ENTER       47                      334
 745  ENTER       48                      335
*                           SOUTHERN AMPHIBIOUS VEHICLE FLOW
*VEHICLES MOVE FROM LD TO CROSSING SITES,CROSS RIVER AND MOVE TO ALIGNMENT AREA
*ON FAR BANK.
*THIS FLOW BEGINS AT CANB-LD AND CARRIES VEH TO THE FAR BANK CAFB
 140  ADVANCE                      BOTH   141    260
 141  COMPARE     P1    E     K1          142
 142  ASSIGN      4     K7                143                           P4 VEL 7KPH
 143  ASSIGN      5     V1                144                           TM=4-7KM/7KPH
 144  ADVANCE                      PICK   145    147     *5             TT LD-CS5,6,7
 145  ASSIGN      8     K5                148                           CSNB-CSFB
 146  ASSIGN      8     K6                149                           CSNB-CSFB
 147  ASSIGN      8     K7                150                           CSNB-CSFB
 148  QUEUE       1                       151                           CS7NB Q
 149  QUEUE       2                       152                           CS6NB Q
 150  QUEUE       3                       153                           CS5NB Q
 151  ENTER       2                       154                           S C1 EN CS7NB
 152  ENTER       3                       155                           S C1 EN CS6NB
 153  ENTER       4                       156                           S C1 EN CS5NB
 154  LEAVE       1                       157            8      3
 155  LEAVE       1                       158            8      3
 156  LEAVE       1                       159            8      3
 157  LEAVE       2                       160
 158  LEAVE       3                       160
 159  LEAVE       4                       160
 160  ASSIGN      2     V2                161                           TT RIVER
 161  QUEUE       4                       162            *2             TM IN RIVER
 162  GATE        SNF*8            FN     17                            CSNB-CSFB
 163  STORE       5                       166            10     5       S5 CS7FB
 164  STORE       6                       166            10     5       S6 CS6FB
 165  STORE       7                       166            10     5       S7 CS5FB
 166  ENTER       16               BOTH   167    169                    CAFB
 167  COMPARE     P3    E     K1          168
 168  SAVEX       13    C1                169                           TM SC1 X RIVER
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 169  ADVANCE                           ALL   170    176                      SEG BY UNIT
 170  COMPARE    P6      E      K1      BOTH  450    500                      U1 TF1-78
 171  COMPARE    P6      E      K2      BOTH  460    501                      U2 1-76
 172  COMPARE    P6      E      K6      BOTH  730    740                      U6 BDE TAC CP
 173  COMPARE    P6      E      K8            219                             U8 ENGR
 174  COMPARE    P6      E      K7            233
 175  COMPARE    P6      E      K4      BOTH  641    648                      U4 1-4ARMOR
 176  ADVANCE                                 799                             EXTRA
*                            NORTHERN AMPHIBIOUS VEHICLE FLOW
 177  ADVANCE                           BOTH  178    350
 178  COMPARE    P1      E      K1            179
 179  ASSIGN     4       K7                   180                             P4 VEL 7KPH
 180  ASSIGN     5       V1                   181                             TM=4-7KM/7KPH
 181  ADVANCE                           PICK  182    184    *5               TT LD-CS2,3,4
 182  ASSIGN     8       K11                  185                             CSNB-CSFB
 183  ASSIGN     8       K12                  186                             CSNB-CSFB
 184  ASSIGN     8       K13                  187                             CSNB-CSFB
 185  QUEUE      5                            188                             CS4NB Q
 186  QUEUE      6                            189                             CS3NB Q
 187  QUEUE      7                            190                             CS2NB Q
 188  ENTER      8                            191                             S C1 EN CS4NB
 189  ENTER      9                            192                             S C1 EN CS3NB
 190  ENTER      10                           193                             S C1 EN CS2NB
 191  LEAVE      1                            194           8      3
 192  LEAVE      1                            195           8      3
 193  LEAVE      1                            196           8      3
 194  LEAVE      8                            197
 195  LEAVE      9                            197
 196  LEAVE      10                           197
 197  ASSIGN     2       V2                   198                             TT RIVER
 198  QUEUE      8                            199           *2                TM IN RIVER
 199  GATE       SNF*8                  FN    18                              CSNB-CSFB
 200  STORE      11                           203           10     5          S11 CS4FB
 201  STORE      12                           203           10     5          S12 CS3FB
 202  STORE      13                           203           10     5          S13 CS2FB
 203  ENTER      16                     BOTH  204    206                      CAFB
 204  COMPARE    P3      E      K1            205
 205  SAVEX      14      C1                   206                             TM NC1 X RIVER
 206  ADVANCE                           ALL   207    213                      SEG BY UNIT
 207  COMPARE    P6      E      K3      BOTH  550    600                      U3 TF1-77
 208  COMPARE    P6      E      K5      BOTH  560    601                      U5 1-23CAV
 209  COMPARE    P6      E      K8            239                             U8 ENGR
 210  COMPARE    P6      E      K6            730
 211  COMPARE    P6      E      K7            799                             U7 AAA
 212  COMPARE    P6      E      K4      BOTH  680    687                      U4 1-4ARMOR
 213  ADVANCE                                 725                             U11-12ATCHARTY
*                            ENGINEER UNITS MOVE TO RIVER,RECON NB-FB
 215  ASSIGN     4       K7                   216                             P4 VEL 7KPH
 216  ASSIGN     5       V1                   217                             TM=4-7KM/7KPH
 217  ADVANCE                           BOTH  218    225    *5               TT LD-RIVER
 218  COMPARE    P1      E      K1            145                             C1 SWIM
 219  ADVANCE                                 220           1200   300        RECCE
 220  SAVEX      8       C1                   495                             TM RECCE FIN S
 495  ENTER      16                           221
 221  ENTER      17                           224                             EN ENGR PK FBS
 224  SAVEX      71      C1                   799                             TM ENPFBS FULL
 225  ADVANCE                           BOTH  98     226
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 98   COMPARE    N225  E     K1          99
 99   SAVEX      9     C1                226
 226  ADVANCE                            227         1200   300    RECCE
 227  ENTER      18                      230                       EN ENGR PK NBS
 230  SAVEX      72    C1                799                       TM EPNBS FULL
 235  ASSIGN     4     K7                236                       P4 VEL 7KPH
 236  ASSIGN     5     V1                237                       TM=4-7KM/7KPH
 237  ADVANCE                      BOTH  238   245   *5            TT RIVER
 238  COMPARE    P1    E     K1          182                       C1 SWIM
 239  ADVANCE                            240         1200   300    RECCE
 240  SAVEX      10    C1                496                       TM RECCE FIN N
 496  ENTER      16                      241
 241  ENTER      19                      244                       EN ENGR PK FBN
 244  SAVEX      73    C1                799                       TM ENPFBN FULL
 245  ADVANCE                      BOTH  107   246
 107  COMPARE    N245  E     K1          108
 108  SAVEX      11    C1                246
 246  ADVANCE                            247         1200   300    RECCE
 247  ENTER      20                      250                       EN ENGR PK NBN
 250  SAVEX      74    C1                799                       TM EPNBN FULL
*                      SOUTHERN C2-4 VEHICLE SECTION
*NON-AMPHIBIOUS VEHICLES MOVE FROM LD-DA-RIVER ALL C2 AND C3 VEH USE M4T6 OR MAB
*RHFTS C4 VEH USE LTR
 260  ASSIGN     4     K7                261                       P4 VEL 7KPH
 261  ASSIGN     5     V3                262                       TM=2-3KM/7KPH
 262  MARK       7                       263
 263  ADVANCE                      ALL   264   270   *5            TT LD-DAS 2-3K
 264  COMPARE    P6    E     K1          271
 265  COMPARE    P6    E     K2          272
 266  COMPARE    P6    E     K6          273
 267  COMPARE    P6    E     K8          274
 268  COMPARE    P6    E     K7          275
 269  COMPARE    P6    E     K4          276
 270  ADVANCE                            277
 271  SAVEX      75    C1                278                       U1C2-4CL DASNB
 272  SAVEX      76    C1                278                       U2C2-4CL DASNB
 273  SAVEX      77    C1                278                       U6C2-4CL DASNB
 274  SAVEX      78    C1                278                       U8C2-4CL DASNB
 275  SAVEX      79    C1                278                       U7C2-4CL DASNB
 276  SAVEX      80    C1                278                       U4C2-4CL DASNB
 277  SAVEX      81    C1                278                       U9C2-4CL DASNB
 278  TABULATE   1                 BOTH  279   311
 279  COMPARE    P1    E     K4          280
 280  ASSIGN     7     FN11              281
*ABOVE ASSIGNS PRIORITIES U1C4PR3 U2C4PR2 U4C4PR0 U6C4PR1
 281  PRIORITY   *7                      478
 478  ASSIGN     8     K1                282
 282  LINK       9     PR1         ALL   283   288
 283  ENTER      43                      251
 284  ENTER      44                      252
 285  ENTER      45                      253
 286  ENTER      46                      254
 287  ENTER      47                      255
 288  ENTER      48                      256
 251  COMPARE    C1    GE    K5443 BOTH  295   296   *5
 252  COMPARE    C1    GE    K5443 BOTH  297   298   *5
 253  COMPARE    C1    GE    K5443 BOTH  299   300   *5
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254	COMPARE	C1	GE	K10843BOTH		327	328	*5
255	COMPARE	C1	GE	K10843BOTH		329	330	*5
256	COMPARE	C1	GE	K6163 BOTH		331	332	*5
257	LEAVE	43				308		
258	LEAVE	44				309		
259	LEAVE	45				405		
703	LEAVE	46				340		
704	LEAVE	47				341		
705	LEAVE	48				342		
317	LINK	13	PR1		ALL	286	288	
479	ASSIGN	8	K2			317		
289	UNLINK	9	K1	283		406		
290	UNLINK	9	K1	284		407		
291	UNLINK	9	K1	285		408		
318	UNLINK	13	K1	286		343	321	
319	UNLINK	13	K1	287		344	322	
320	UNLINK	13	K1	288		346	323	
321	UNLINK	9	K1	286		343		
322	UNLINK	9	K1	287		344		
323	UNLINK	9	K1	288		346		
295	COMPARE	C1	GE	V4		527		
527	TABULATE	3				301		
296	LINK	1	PR1			295		
297	COMPARE	C1	GE	V4		302		
298	LINK	2	PR1			297		
299	COMPARE	C1	GE	V4		303		
300	LINK	3	PR1			299		
327	COMPARE	C1	GE	V5		528		
528	TABULATE	4				333		
328	LINK	4	PR1			327		
329	COMPARE	C1	GE	V5		334		
330	LINK	5	PR1			329		
331	COMPARE	C1	GE	V6		529		
529	TABULATE	5				335		
14	GENERATE		1			439		1
439	COMPARE	C1	GE	V4		440		
440	UNLINK	1	ALL	301		441		
441	UNLINK	2	ALL	302		442		
442	UNLINK	3	ALL	303		443		
443	COMPARE	C1	GE	V6		445		
445	UNLINK	6	ALL	335		446		
446	COMPARE	C1	GE	V5		447		
447	UNLINK	4	ALL	333		54		
54	UNLINK	5	ALL	334		800		
332	LINK	6	PR1			331		
301	QUEUE	10				304		
302	QUEUE	11				305		
303	QUEUE	12				306		
333	QUEUE	14				337		
334	QUEUE	15				338		
335	QUEUE	16				339		
304	ENTER	72				257		
305	ENTER	73				258		
306	ENTER	74				259		
337	ENTER	75	P8			703		
338	ENTER	76	P8			704		
339	ENTER	77	P8			705		

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 308  LEAVE      1                        289
 309  LEAVE      1                        290
 405  LEAVE      1                        291
 340  LEAVE      1                        318
 341  LEAVE      1                        319
 342  LEAVE      1                        320
 406  ADVANCE                             438         1     FN16
 407  ADVANCE                             436         1     FN16
 408  ADVANCE                             437         1     FN16
 343  ADVANCE                             347         1     FN16
 344  ADVANCE                             348         1     FN16
 346  ADVANCE                             349         1     FN16
 438  LEAVE      72                       639
 639  SAVEX      127   C1                 310                     LTR 5
 436  LEAVE      73                       578
 578  SAVEX      128   C1                 310                     LTR 6
 437  LEAVE      74                       579
 579  SAVEX      129   C1                 310                     LTR 7
 347  LEAVE      75    P8                 586
 586  SAVEX      130   C1                 345                     M4T6 3
 348  LEAVE      76    P8                 587
 587  SAVEX      131   C1                 345                     M4T6 4
 349  LEAVE      77    P8                 229
 229  SAVEX      132   C1                 345                     MAB 2
 310  ENTER      16               ALL     170   176               S16 CAFB
 311  ADVANCE                     BOTH    312   315
 312  COMPARE    P1    E    K2            313
 313  ASSIGN     7     FN10               314
*ABOVE ASSIGNS PRIORITIES U1C2-PR7 U2C2-PR6 U4C2-PR4 U6C2-PR5
 314  PRIORITY   *7                       479
 315  ASSIGN     7     FN11               316
*ABOVE ASSIGNS PRIORITIES U1C3PR3 U2C3PR2 U4C3PR0 U6C3PR1
 316  PRIORITY   *7                       479
 345  ENTER      16               ALL     170   176               S16 CAFB
*                  NORTHERN C2-4 VEHICLE SECTION
*THIS SECTION IS THE SAME AS SOUTHERN EXCEPT FOR AN ADDITIONAL LTR
 350  ASSIGN     4     K7                 351
 351  ASSIGN     5     V3                 352
 352  MARK       7                        353
 353  ADVANCE                     ALL     354   360   *5
 354  COMPARE    P6    E    K3            361
 355  COMPARE    P6    E    K5            362
 356  COMPARE    P6    E    K8            363
 357  COMPARE    P6    E    K6            364
 358  COMPARE    P6    E    K7            365
 359  COMPARE    P6    E    K4            366
 360  ADVANCE                             367
 361  SAVEX      82    C1                 368                     U3C2-4CL DANNB
 362  SAVEX      83    C1                 368                     U5C2-4CL DANNB
 363  SAVEX      84    C1                 368                     U8C2-4CL DANNB
 364  SAVEX      85    C1                 368                     U6C2-4CL DANNB
 365  SAVEX      86    C1                 368                     U7C2-4CL DANNB
 366  SAVEX      87    C1                 368                     U4C2-4CL DANNB
 367  SAVEX      88    C1                 368                     U9C2-4CL DANNB
 368  TABULATE   2                BOTH    369   410
 369  COMPARE    P1    E    K4            370
 370  ASSIGN     7     FN14               371
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*ASSIGNS FOLLOWING PRIORITIES U3C4PR3 U5C4PR2 U4C4PR0 U6C4PR1
 371  PRIORITY     *7                       513
 513  ASSIGN       8     K1                 372
 372  LINK         17    PR1          ALL   373   379
 514  ASSIGN       8     K2                 416
 416  LINK         18    PR1          ALL   377   379
 373  ENTER        53                       706
 374  ENTER        54                       717
 375  ENTER        55                       718
 376  ENTER        56                       719
 377  ENTER        57                       720
 378  ENTER        58                       791
 379  ENTER        59                       792
 706  COMPARE      C1    GE   K5539 BOTH    388   389   *5
 717  COMPARE      C1    GE   K5539 BOTH    390   391   *5
 718  COMPARE      C1    GE   K5539 BOTH    392   393   *5
 719  COMPARE      C1    GE   K5539 BOTH    394   395   *5
 720  COMPARE      C1    GE   K10939BOTH    530   531   *5
 791  COMPARE      C1    GE   K10939BOTH    532   533   *5
 792  COMPARE      C1    GE   K6259 BOTH    534   535   *5
 793  LEAVE        53                       417
 794  LEAVE        54                       418
 796  LEAVE        55                       419
 797  LEAVE        56                       420
 798  LEAVE        57                       542
 700  LEAVE        58                       543
 214  LEAVE        59                       544
 380  UNLINK       17    K1   373           421
 381  UNLINK       17    K1   374           422
 382  UNLINK       17    K1   375           423
 383  UNLINK       17    K1   376           424
 429  UNLINK       18    K1   377           545   432
 430  UNLINK       18    K1   378           546   433
 431  UNLINK       18    K1   379           547   434
 432  UNLINK       17    K1   377           545
 433  UNLINK       17    K1   378           546
 434  UNLINK       17    K1   379           547
 388  COMPARE      C1    GE   V13           712
 712  TABULATE     6                        396
 389  LINK         7     PR1                388
 390  COMPARE      C1    GE   V13           397
 391  LINK         8     PR1                390
 392  COMPARE      C1    GE   V13           398
 393  LINK         10    PR1                392
 394  COMPARE      C1    GE   V13           399
 395  LINK         11    PR1                394
 530  COMPARE      C1    GE   V14           713
 713  TABULATE     7.                       536
 531  LINK         12    PR1                530
 532  COMPARE      C1    GE   V14           537
 533  LINK         14    PR1                532
 534  COMPARE      C1    GE   V15           714
 714  TABULATE     8                        538
 124  GENERATE           1                  125         1
 125  COMPARE      C1    GE   V13           242
 242  UNLINK       7     ALL  396           243
 243  UNLINK       8     ALL  397           248
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 248  UNLINK     10    ALL   398         249
 249  UNLINK     11    ALL   399         134
 134  COMPARE    C1    GE    V15         135
 135  UNLINK     15    ALL   538         136
 136  COMPARE    C1    GE    V14         137
 137  UNLINK     12    ALL   536         138
 138  UNLINK     14    ALL   537         800
 535  LINK       15    PR1               534
 396  QUEUE      18                      400
 397  QUEUE      19                      401
 398  QUEUE      20                      402
 399  QUEUE      21                      403
 536  QUEUE      23                      539
 537  QUEUE      24                      540
 538  QUEUE      25                      541
 400  ENTER      80                      793
 401  ENTER      81                      794
 402  ENTER      82                      796
 403  ENTER      83                      797
 539  ENTER      84    P8                798
 540  ENTER      85    P8                700
 541  ENTER      86    P8                214
 417  LEAVE      1                       380
 418  LEAVE      1                       381
 419  LEAVE      1                       382
 420  LEAVE      1                       383
 542  LEAVE      1                       429
 543  LEAVE      1                       430
 544  LEAVE      1                       431
 421  ADVANCE                            425          1     FN16
 422  ADVANCE                            426          1     FN16
 423  ADVANCE                            427          1     FN16
 424  ADVANCE                            428          1     FN16
 545  ADVANCE                            548          1     FN16
 546  ADVANCE                            549          1     FN16
 547  ADVANCE                            789          1     FN16
 425  LEAVE      80                      752
 752  SAVEX      120   C1                409                     LTR 1
 426  LEAVE      81                      753
 753  SAVEX      121   C1                409                     LTR 2
 427  LEAVE      82                      754
 754  SAVEX      122   C1                409                     LTR 3
 428  LEAVE      83                      755
 755  SAVEX      123   C1                409                     LTR 4
 548  LEAVE      84    P8                435
 435  SAVEX      124   C1                444                     M4T6 1
 549  LEAVE      85    P8                448
 448  SAVEX      125   C1                444                     M4T6 2
 789  LEAVE      86    P8                449
 449  SAVEX      126   C1                444                     MAB 1
 409  ENTER      16               ALL    207    213              S16 CAFB
 410  ADVANCE                     BOTH   411    414
 411  COMPARE    P1    E     K2          412
 412  ASSIGN     7     FN13              413
*ASSIGNS FOLLOWING PRIORITIES U3C2PR7 U5C2PR6 U4C2PR5 U6C2PR4
 413  PRIORITY   *7                      514
 414  ASSIGN     7     FN14              415
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*ASSIGNS FOLLOWING PRIORITIES  U3C3PR3 U5C3PR2 U4C3PR0 U6C3PR1
 415  PRIORITY     *7                              514
 444  ENTER        16                  ALL         207    213                  S16 CAFB
*                           SOUTHERN C1 VEH MOVT FROM RIVER-PL-OBJ
 450  COMPARE      P1     E      K1                451                         U1
 451  SAVEX        25     C1                       452                         TM U1C1CL CAFB
 452  ENTER        29                              453                         U1 ALIGN AREA
 453  GATE         LS1                             454
 454  LOGIC        I1                              455
 455  LEAVE        29                              470
 456  GENERATE     0      109                      457           3      1
 457  COMPARE      N452   GE     K109              458
 458  LOGIC        I1                              800
 460  COMPARE      P1     E      K1                461                         U2
 461  SAVEX        26     C1                       462                         TM U2C1CL CAFB
 462  ENTER        30                              463                         U2 ALIGN AREA
 463  GATE         LS2                             464
 464  LOGIC        I2                              465
 465  LEAVE        30                              470
 466  GENERATE     0      68                       467           3      1
 467  COMPARE      N462   GE     K68               468
 468  LOGIC        I2                              800
 470  ASSIGN       2      V1                       471
 471  ADVANCE                                      472           *2            TT FB-PL 4-6KM
 472  LEAVE        16                              473                         LV CAFB
 473  ENTER        31                  BOTH        474    476    1             U1U2U6 AR PL
 474  COMPARE      P6     E      K1                475
 475  SAVEX        29     C1                       477                         TM U1C1 CL PL
 476  SAVEX        30     C1                       477                         TM U2C1 CL PL
 477  LEAVE        31                              480
 480  ASSIGN       2      V7                       481                         TT PL-OBJ S
 481  ADVANCE                                      482           *2
 482  ENTER        32                              483           1             S32 U1U2 OBJ
 483  LEAVE        32                  ALL         484    486
 484  COMPARE      P6     E      K1    BOTH        489    491
 489  COMPARE      P1     E      K1                490
 490  SAVEX        31     C1                       799                         TM U1C1 CL OBJ
 491  SAVEX        33     C1                       799                         TM U1C2-4 CL
 485  COMPARE      P6     E      K2    BOTH        492    494
 492  COMPARE      P1     E      K1                493
 493  SAVEX        32     C1                       799                         TM U2C1 CL OBJ
 494  SAVEX        34     C1                       799                         TM U2C2-4 CL
 486  COMPARE      P6     E      K6                497
 497  SAVEX        98     C1                       799                         TM U6C1 CL OBJ
*                           SOUTHERN C2-4 VEH MOVT FROM RIVER-DA-HA-OBJ
 500  SAVEX        27     C1                       502                         TMU1C2-4CLCAFB
 501  SAVEX        35     C1                       502                         TMU2C2-4CLCAFB
 502  ADVANCE                                      503           *5            TT RIVER-DASFB
 503  ENTER        25                  BOTH        504    508                  S25 DASFB
 504  COMPARE      P6     E      K1                505
 505  SAVEX        36     C1                       506                         TMU1C2-4CLDASF
 506  ENTER        26                              507           1             U1AREA DASFB
 507  LEAVE        26                              511
 508  SAVEX        37     C1                       509                         TMU2C2-4CLDASF
 509  ENTER        27                              510           1             U2AREA DASFB
 510  LEAVE        27                              511
 511  LEAVE        25                              325
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 325  LEAVE      16                            512
 512  ASSIGN     5      V8                     515
 515  ADVANCE                                  516          *5          TT OA-HA 4-6KM
 516  ENTER      68                 BOTH       517    521               S68 HASFB
 517  COMPARE    P6     E     K1               518
 518  SAVEX      38     C1                     519                      TMU1C2-4CLHASF
 519  ENTER      66                            520          1           U1AREA HASFB
 520  LEAVE      66                            524
 521  SAVEX      39     C1                     522                      TMU2C2-4CLHASF
 522  ENTER      67                            523          1           U2AREA HASFB
 523  LEAVE      67                            524
 524  LEAVE      68                            525
 525  ASSIGN     5      V9                     526                      TT HASFB-OBJ
 526  ADVANCE                                  482          *5          D=11-13KM
*                       SOUTHERN AAA BTRY(-) MOVT SECTION RIVER TO
*                       ALL VEHICLES FROM RIVER TO PL
 233  ASSIGN     2      V10                    751
 751  SAVEX      101    C1                     234
 234  ADVANCE                                  487          *2
 487  LEAVE      16                            488
 488  SAVEX      102    C1                     799                      TM U7S CL PL
*                       NORTHERN C1 VEH MOVT FROM RIVER-PL-OBJ
 550  COMPARE    P1     E     K1               551
 551  SAVEX      40     C1                     552                      TM U3C1CL CAFB
 552  ENTER      33                            553                      U3 ALIGN
 553  GATE       LS3                           554
 554  LOGIC      I3                            555
 555  LEAVE      33                            570
 556  GENERATE   0      109                    557          3      1
 557  COMPARE    N552   GE    K109             558
 558  LOGIC      I3                            800
 560  COMPARE    P1     E     K1               561
 561  SAVEX      41     C1                     562                      TMU5C1 CL CAFB
 562  ENTER      34                            563                      U5 ALIGN
 563  GATE       LS4                           564
 564  LOGIC      I4                            565
 565  LEAVE      34                            570                      LV ALIGN
 566  GENERATE   0      117                    567          3      1
 567  COMPARE    N562   GE    K117             568
 568  LOGIC      I4                            800
 570  ASSIGN     2      V10                    571                      TT RIVER-PL N
 571  ADVANCE                                  572          *2          D=5.5-6.5KM
 572  LEAVE      16                            573                      LV CAFB
 573  ENTER      35                 BOTH       574    576   1           U3U5 AR PL
 574  COMPARE    P6     E     K3               575
 575  SAVEX      42     C1                     577                      TM U3 C1 CL PL
 576  SAVEX      43     C1                     577                      TM U5 C1 CL PL
 577  LEAVE      35                            580
 580  ASSIGN     2      V11                    581                      TT PL-OBJ U3U5
 581  ADVANCE                                  582          *2          D=9-12KM
 582  ENTER      36                            583          1           S36 U3U5 OBJ
 583  LEAVE      36                 BOTH       584    585
 584  COMPARE    P6     E     K3    BOTH       588    590
 588  COMPARE    P1     E     K1               589
 589  SAVEX      44     C1                     799                      TM U3C1 CL OBJ
 590  SAVEX      45     C1                     799                      TMU3C2-4CL OBJ
 585  COMPARE    P6     E     K5    BOTH       591    593
```

```
 591  COMPARE      P1     E      K1             592
 592  SAVEX        46     C1                    799                          TM U5C1 CL OBJ
 593  SAVEX        47     C1                    799                          TMU5C2-4CL OBJ
*                         NORTHERN C2-4 VEH MOVT FROM RIVER-DA-HA-OBJ
 600  SAVEX        48     C1                    602                          TMU3C2-4CLCAFB
 601  SAVEX        49     C1                    602                          TMU5C2-4CLCAFB
 602  ADVANCE                                   603             *5           TT RIVER-DANFB
 603  ENTER        37                   BOTH    604     608                  S37 DANFB
 604  COMPARE      P6     E      K3             605
 605  SAVEX        50     C1                    606                          TMU3C2-4CLDANF
 606  ENTER        38                           607              1           U3 AREA DANFB
 607  LEAVE        38                           611
 608  SAVEX        51     C1                    609                          TMU5C2-4CLDANF
 609  ENTER        39                           610              1           U5 AREA DANFB
 610  LEAVE        39                           611
 611  LEAVE        37                           326
 326  LEAVE        16                           612
 612  ASSIGN       5      V8                    613                          TT DANFB-HANFB
 613  ADVANCE                                   614             *5           D=4-6KM
 614  ENTER        40                   BOTH    615     619                  S40 HANFB
 615  COMPARE      P6     E      K3             616
 616  SAVEX        52     C1                    617                          TMU3C2-4CLHANF
 617  ENTER        41                           618              1           U3 AREA HANFB
 618  LEAVE        41                           622
 619  SAVEX        53     C1                    620                          TMU5C2-4CLHANF
 620  ENTER        42                           621              1           U5 AREA HANFB
 621  LEAVE        42                           622
 622  LEAVE        40                           623                          LV HANFB
 623  ASSIGN       5      V9                    624                          TT HANFB-OBJ
 624  ADVANCE                                   582             *5
*                         TF1-4ARMOR MOVT FROM RIVER TO OBJ
 625  LOGIC        I5                   BOTH    626     667
 626  GATE         LS5                          627
 627  ASSIGN       5      V1            ALL     628     630
 628  COMPARE      P1     E      K2             631
 629  COMPARE      P1     E      K1             631
 630  ADVANCE                                   260
 631  ADVANCE                                   632             *5           TT RIVER-FSPNB
 632  ENTER        49                           633                          S49 FSPSNB
 633  SAVEX        57     C1                    634                          TMU4S CL FSPNB
 634  GATE         LS6                          635                          U4C1-2GOTOCAFB
 635  LOGIC        I6                           636                          U1-2CL ALIGN
 636  LEAVE        49                           637                          LV FPSNB
 637  SAVEX        58     C1            BOTH    638     313                  TM U4 CL FSPS
 638  COMPARE      P1     E      K1     PICK    145     147                  GOTOM4T6MAB CS
 641  COMPARE      P1     E      K1             642
 642  SAVEX        59     C1                    643                          TMU4SC1CLALIGN
 643  ENTER        50.                          644                          S50 U4S ALIGN
 644  GATE         LS7                          645
 645  LOGIC        I7                           646
 646  LEAVE        50                           647
 647  ASSIGN       5      V3                    650                          D=2-3KM
 648  ASSIGN       5      V3                    649
 649  SAVEX        60     C1                    650                          TMU4SC2-4CLCAF
 650  ADVANCE                                   651             *5           TT TO AA 2-3KM
 651  ENTER        51                   BOTH    652     654                  S51 U4AA
 652  COMPARE      P1     E      K1             653
```

```
653  SAVEX      61    C1                694                     TM U4C1 CL AAS
654  SAVEX      62    C1                694                     TM U4C2-4 CL
655  GENERATE   0     25                656         3     1
656  COMPARE    N643  GE    K25         657
657  LOGIC      I7                      800
659  GENERATE   0     35                660         3     1
660  COMPARE    N633  GE    K35         665
665  LOGIC      I6                      800
667  ASSIGN     5     V1          ALL   668   670                 D=4-7 KM
668  COMPARE    P1    E     K2          671
669  COMPARE    P1    E     K1          671
670  ADVANCE                            350
671  ADVANCE                            672         *5          TT RIVER-FSPN
672  ENTER      70                      673                     S70 FSPN
673  SAVEX      63    C1                674                     TMU4C1-2CLFSPN
674  GATE       LS10                    675
675  LOGIC      I10                     676
676  LEAVE      70                      677
677  SAVEX      64    C1          BOTH  678   679               TM U4C1-2LVFSP
678  COMPARE    P1    E     K1    PICK  182   184               C1 SWIM
679  ADVANCE                            412                     TO M4T6 MAB N
680  COMPARE    P1    E     K1          681
681  SAVEX      65    C1                682                     TMU4C1CLALIGNN
682  ENTER      71                      683                     S71 ALIGN N U4
683  GATE       LS13                    684
684  LOGIC      I13                     685
685  LEAVE      71                      686
686  ASSIGN     5     V3                689                     2-3KM
687  ASSIGN     5     V3                688                     TT TO AA N
688  SAVEX      66    C1                689                     TMU4C2-4CLCAFB
689  ADVANCE                            690         *5          TT TO AA N
690  ENTER      51                BOTH  691   693               S51 AA
691  COMPARE    P1    E     K1          692
692  SAVEX      67    C1                694                     TMU4C1 CL AAN
693  SAVEX      68    C1                694                     TMU4C2-4 CL AA
694  GATE       LS12                    711
711  LOGIC      I12                     404
404  LEAVE      51                      336
336  LEAVE      16                      696
696  SAVEX      69    C1                697                     TM U4 LV RESAA
697  ASSIGN     5     V12               698                     TT AA-OBJ
698  ADVANCE                            699         *5          D=17-19KM
699  SAVEX      70    C1                799                     TM U4 CL OBJ
701  GENERATE   0     34                702         3     1
702  COMPARE    N673  GE    K34         707
707  LOGIC      I10                     800
709  GENERATE   0     135               710         3     1
710  COMPARE    V19   GE    K86         715
715  LOGIC      I12                     800
222  GENERATE   0     24                223         3     1
223  COMPARE    N682  GE    K24         228
228  LOGIC      I13                     800
*                     TRAINS MOVT SECTION
594  GENERATE   0     306               595         7     1
595  COMPARE    C1    GE    V16         596
596  ASSIGN     6     K9                597                     U9 TRNS
597  ASSIGN     4     K10               598                     P4 VEL 10KPH
```

```
598  ENTER     1                        599                        S1 CANB
599  ASSIGN    5     V10                231                        TT LD-BR 6KM
231  ADVANCE                            232           *5
232  LEAVE     1                        721
721  SAVEX     89    C1                 722                        TM TRNS LVCANB
722  STORE     63                       723           58           S63 BRIDGE
723  SAVEX     104   C1                 724                        TM LAST VEH
724  ENTER     16                       725                        S16 CAFB
725  ASSIGN    5     V17                726                        TT BR-PL 7-6KM
726  ADVANCE                            727           *5
727  LEAVE     16               BOTH    795     728
795  COMPARE   P6    NE    K9           57
57   ADVANCE                    BOTH    58      771
58   COMPARE   P6    E     K7           729
728  SAVEX     90    C1                 799                        TM TRNS LV PL
729  SAVEX     105   C1                 799                        TM U7NLVPL
*                BDE TAC CP MOVT SECTION U6
730  COMPARE   P1    E     K1           731
731  SAVEX     100   C1                 732                        TM U6C1CL CAFB
732  ENTER     60                       733                        S60 U6 ALIGN
733  GATE      LS11                     734
734  LOGIC     I11                      735
735  LEAVE     60                       470
736  GENERATE  0     8                  737           3      1
737  COMPARE   N732  GE    K8           738
738  LOGIC     I11                      800
*                ATCH ARTY MOVT SECTION U11 U12
756  GENERATE  0     102                757           7      1
757  COMPARE   C1    GE    V18          758
758  PRIORITY  7                BOTH    759     761                U11 U12 PR7
759  COMPARE   N758  LE    K72          760
760  ASSIGN    1     K4                 762                        72 C4
761  ASSIGN    1     K3                 762                        30 C3
762  ASSIGN    3     K2                 763                        FS ECHELON
763  SPLIT                              764     778
764  ASSIGN    6     K11                765                        U11 1-651ARTY
765  ENTER     1                        790                        S1 CANB
790  ASSIGN    4     K10                766
766  ASSIGN    5     V10                768                        TT TO BR
767  COMPARE   C1    GE    V16  BOTH    787     769                BR OPEN
768  ADVANCE                            767           *5
787  COMPARE   P6    E     K11          788
788  SAVEX     94    C1                 770                        TM U11 LV CANB
769  SAVEX     93    C1                 770                        TM U12 LV CANB
770  LEAVE     1                BOTH    664     722
664  COMPARE   N770  E     K1           695
695  SAVEX     103   C1                 722                        TM FIRST VEH
771  ENTER     64               BOTH    772     774   1
772  COMPARE   P6    E     K11          773
773  SAVEX     96    C1                 775                        TM U11 CL FPFB
774  SAVEX     97    C1                 775                        TM U12 CL FPFB
775  COMPARE   N771  GE    K204         776
776  LEAVE     64                       777
777  SAVEX     99    C1                 799                        U11 U12 TERM
778  ASSIGN    6     K12                779                        U12 1-652 ARTY
779  ENTER     65                       780                        U12 FP VIC LD
780  GATE      LS15                     781
```

```
 781  LOGIC       I15                          782
 782  LEAVE       65                           765
 783  GENERATE    0      102                   784          7       1
 784  COMPARE     N771   NE      K0            785
 785  LOGIC       I15                          800
*                        VITAL STATISTICS SECTION
 292  GENERATE    0      1                     459          1
 459  COMPARE     N488   E       K58           293
 293  SAVEX       106    V20                   294                        TM LTR 1 USED
 294  SAVEX       107    V21                   661                        TM LTR 2 USED
 661  SAVEX       108    V22                   662                        TM LTR 3 USED
 662  SAVEX       109    V23                   663                        TM LTR 4 USED
 663  SAVEX       110    V24                   746                        TM M4T6 1 USED
 746  SAVEX       111    V25                   747                        TM M4T6 2 USED
 747  SAVEX       112    V26                   748                        TM MAB 1 USED
 748  SAVEX       113    V27                   749                        TM LTR 5 USED
 749  SAVEX       114    V28                   750                        TM LTR 6 USED
 750  SAVEX       115    V29                   324                        TM LTR 7 USED
 324  SAVEX       116    V30                   139                        TM M4T6 3 USED
 139  SAVEX       117    V30                   387                        TM M4T6 4 USED
 387  SAVEX       118    V32                   307                        TM MAB 2 USED
 307  SAVEX       119    V33                   800                        TM BRIDGE USED
 799  TERMINATE   R
 800  TERMINATE
      START       1938           43200

 CLOCK TIME  REL        43035                ABS        43035
```

APPENDIX D

BASE MODEL REPRESENTATIVE GPSS II FLOW DIAGRAM

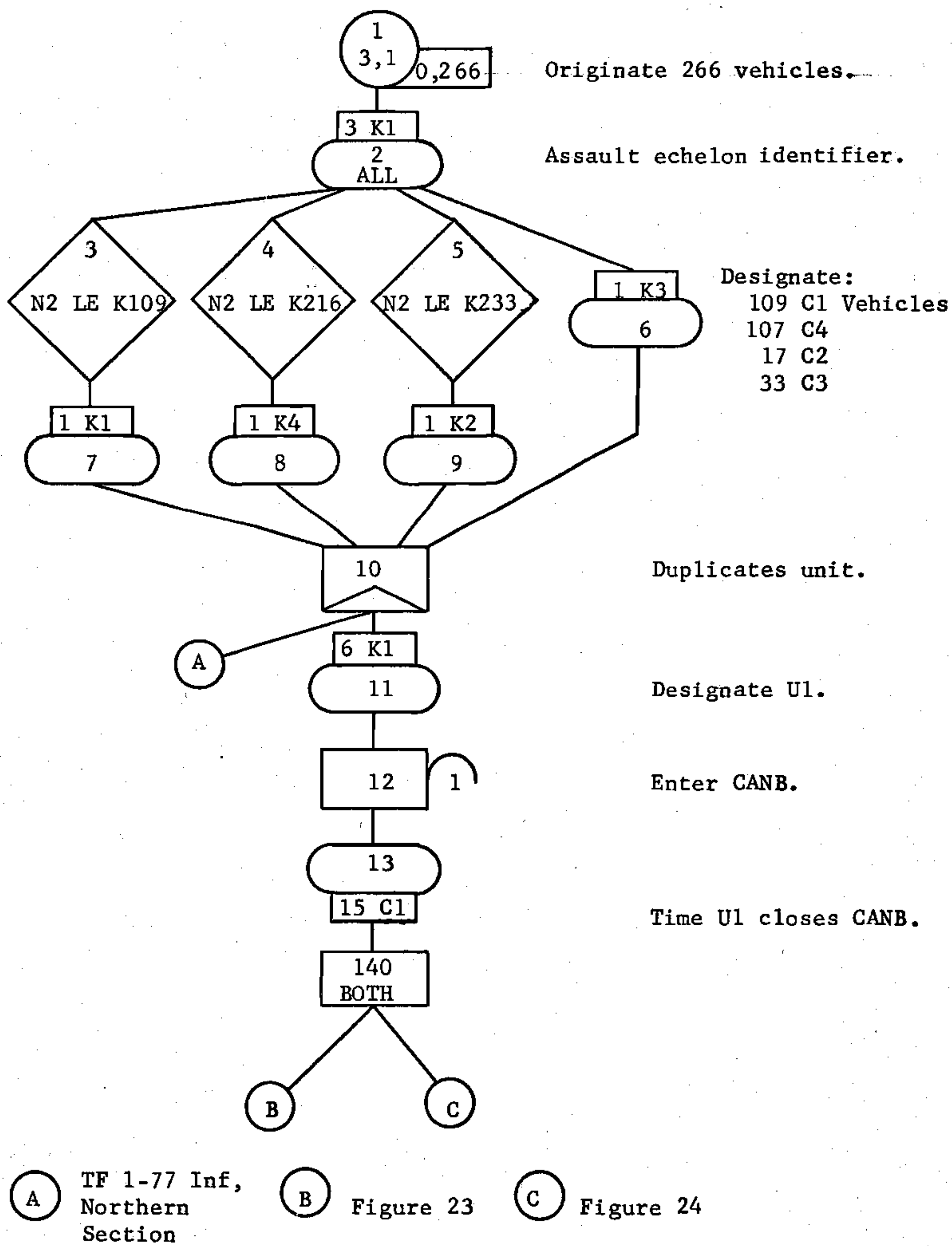


Figure 22. TF 1-78 Infantry Generator

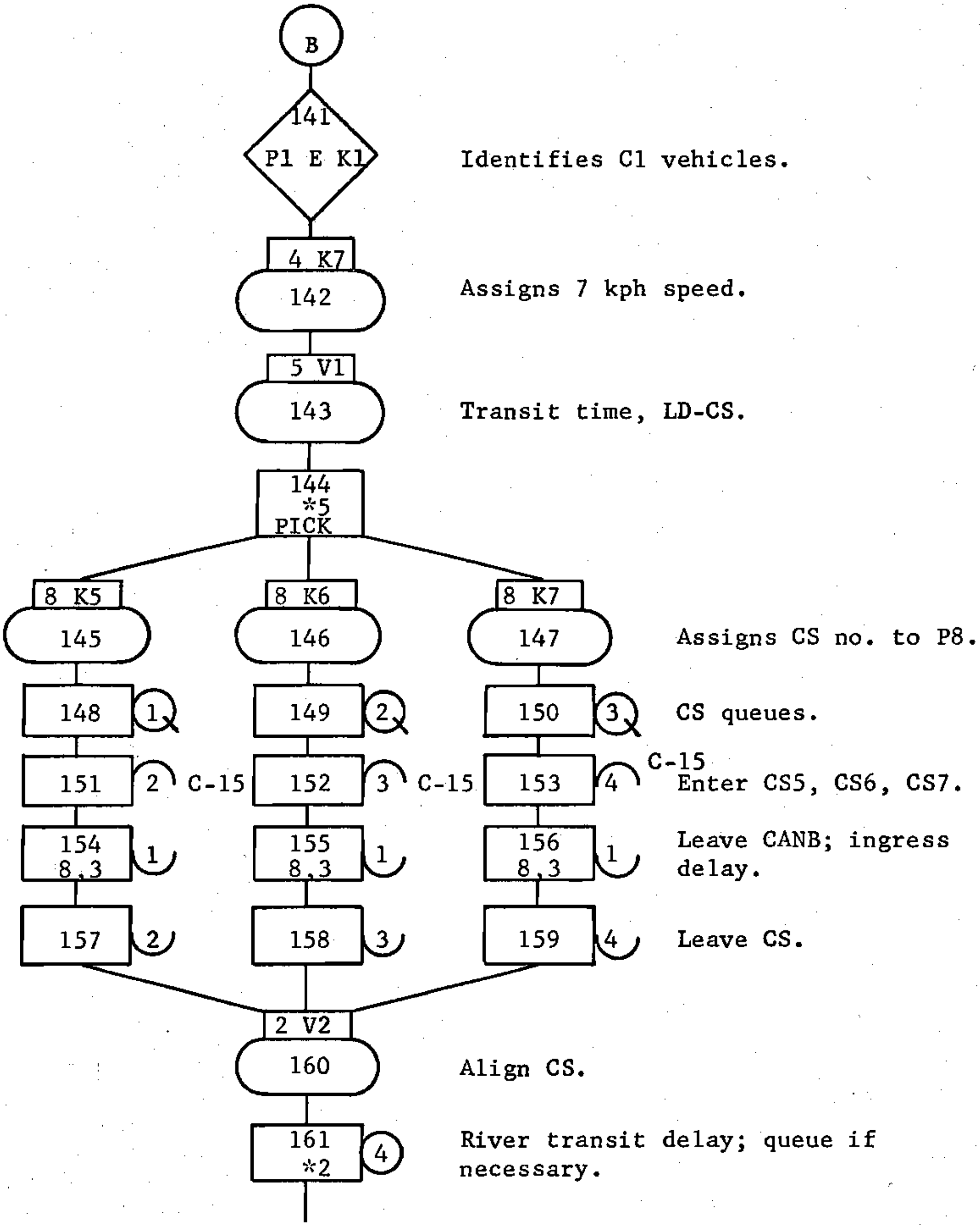
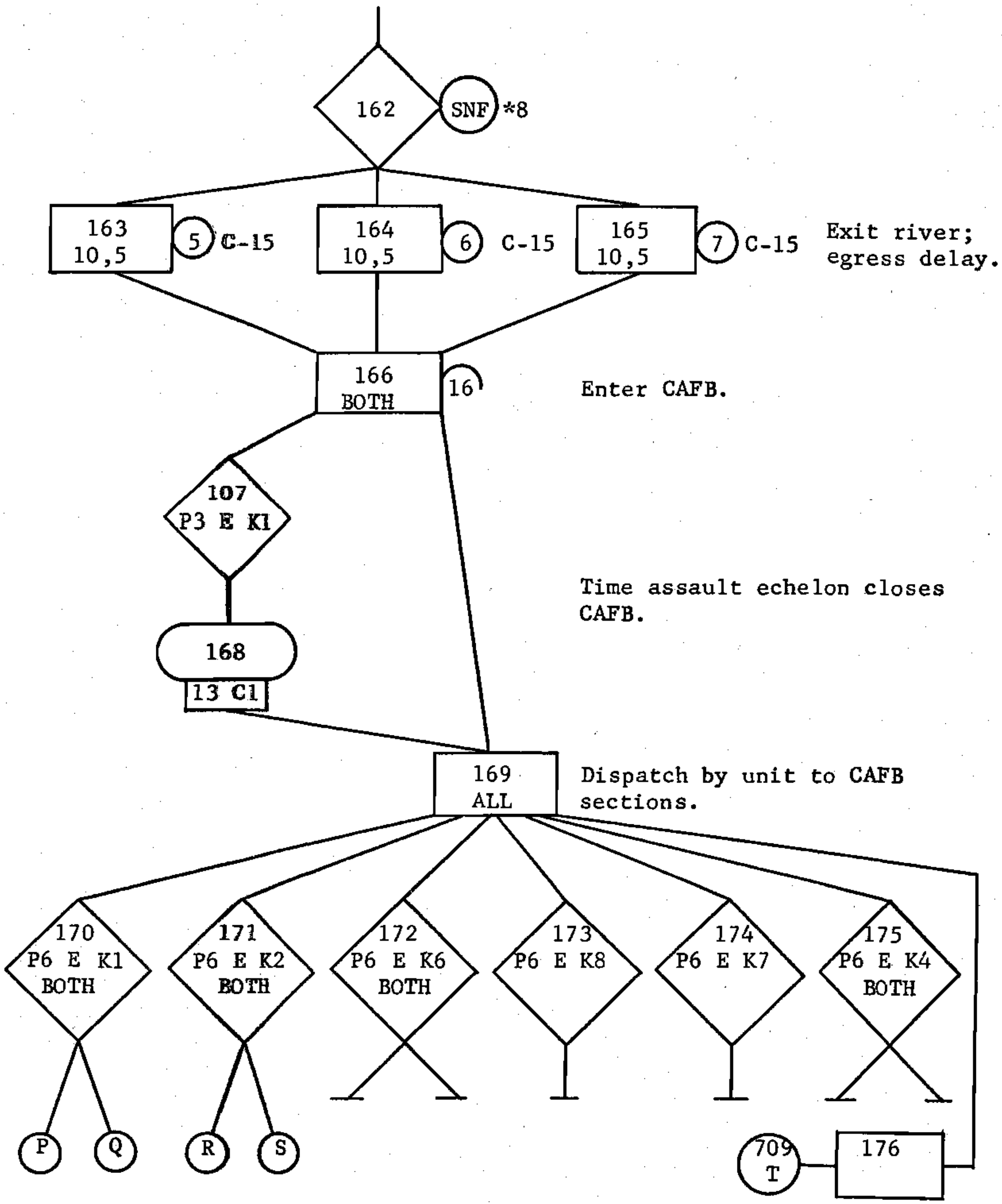


Figure 23. GPSS II Southern Amphibious Vehicle Flow, CANB



P Figure 25 Q Figure 26 R Figure 25 S Figure 26

Figure 23. Concluded

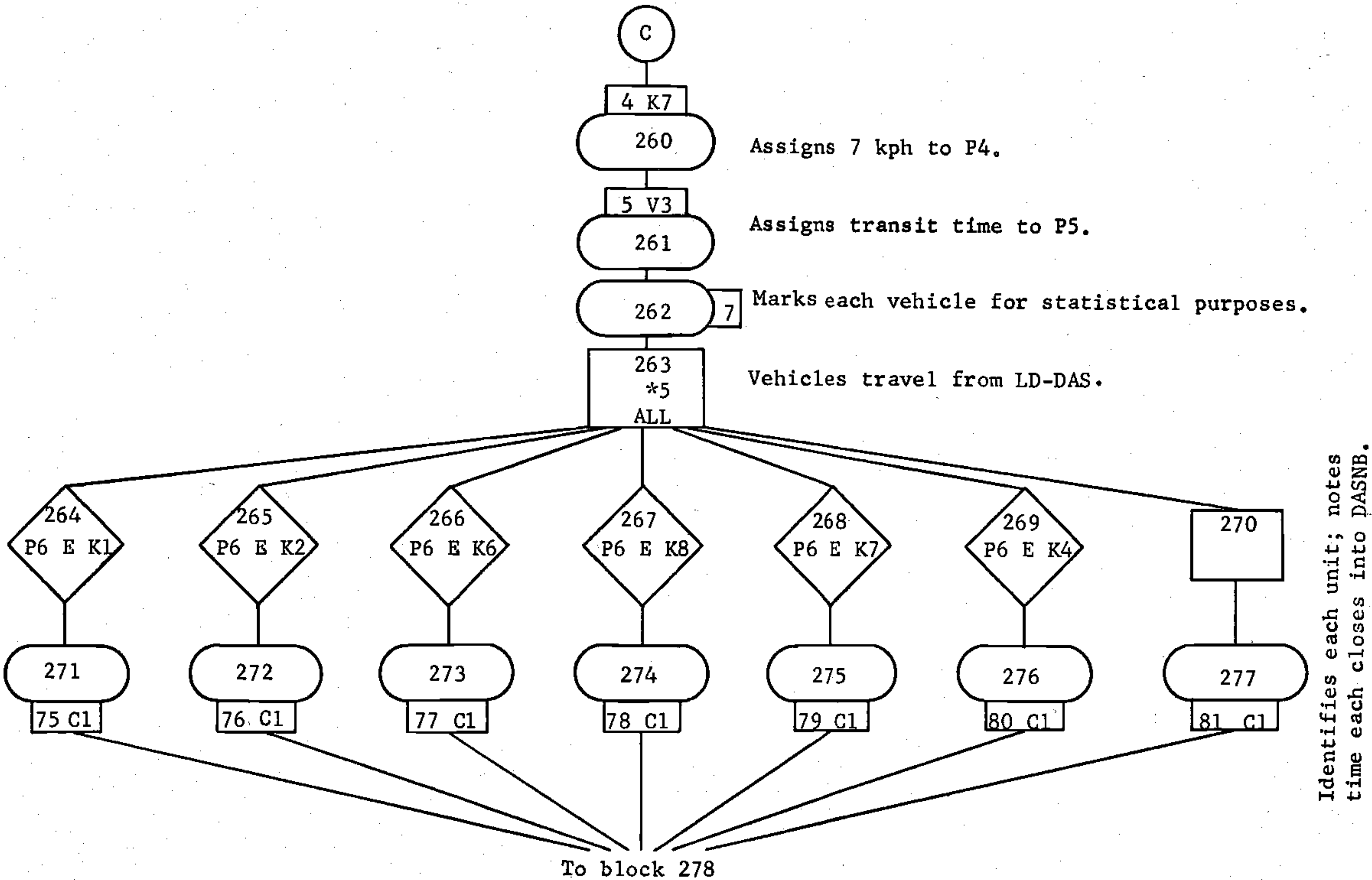


Figure 24. GPSS II Southern Nonamphibious Vehicle Flow, CANB

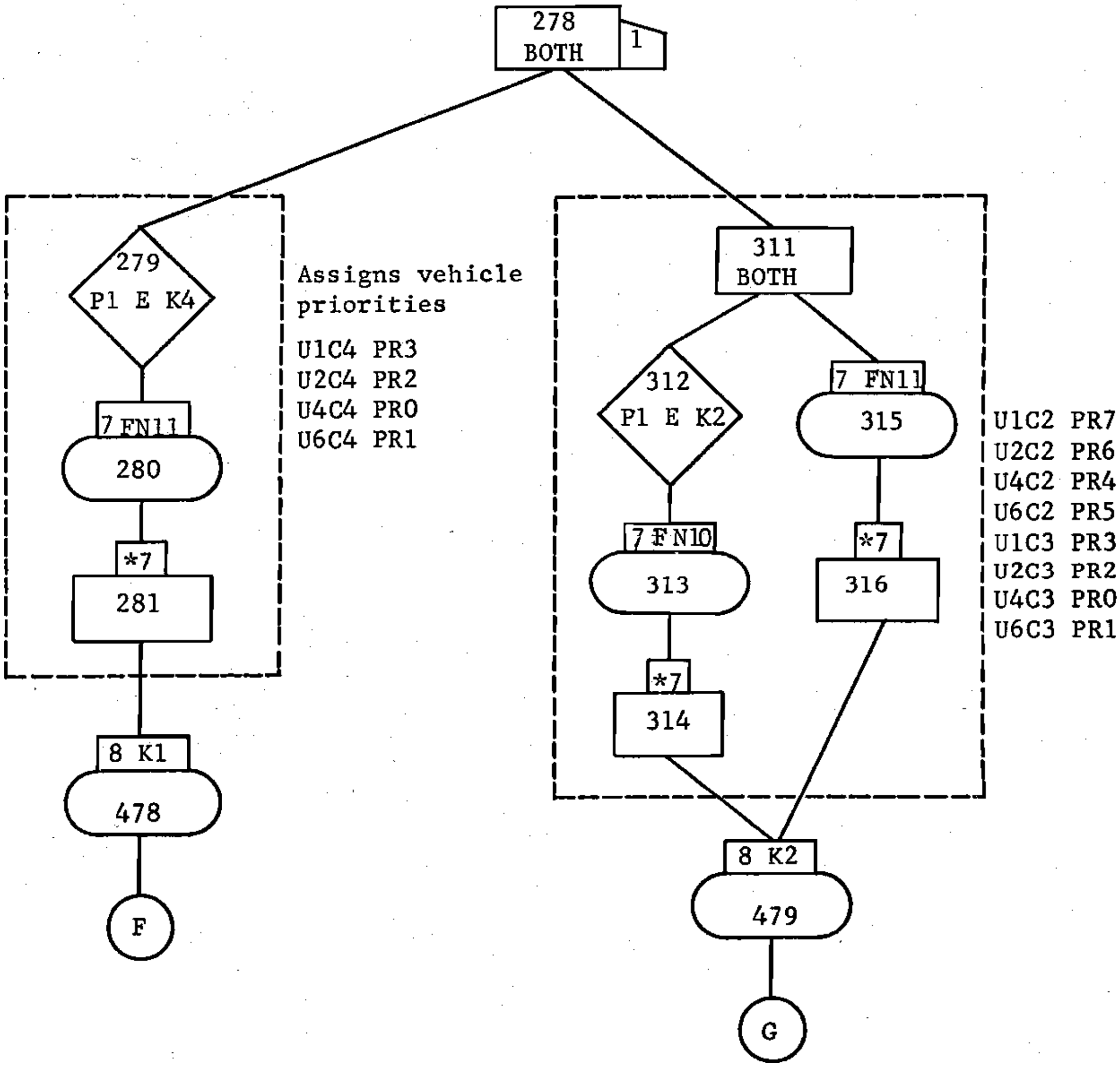


Figure 24. Continued

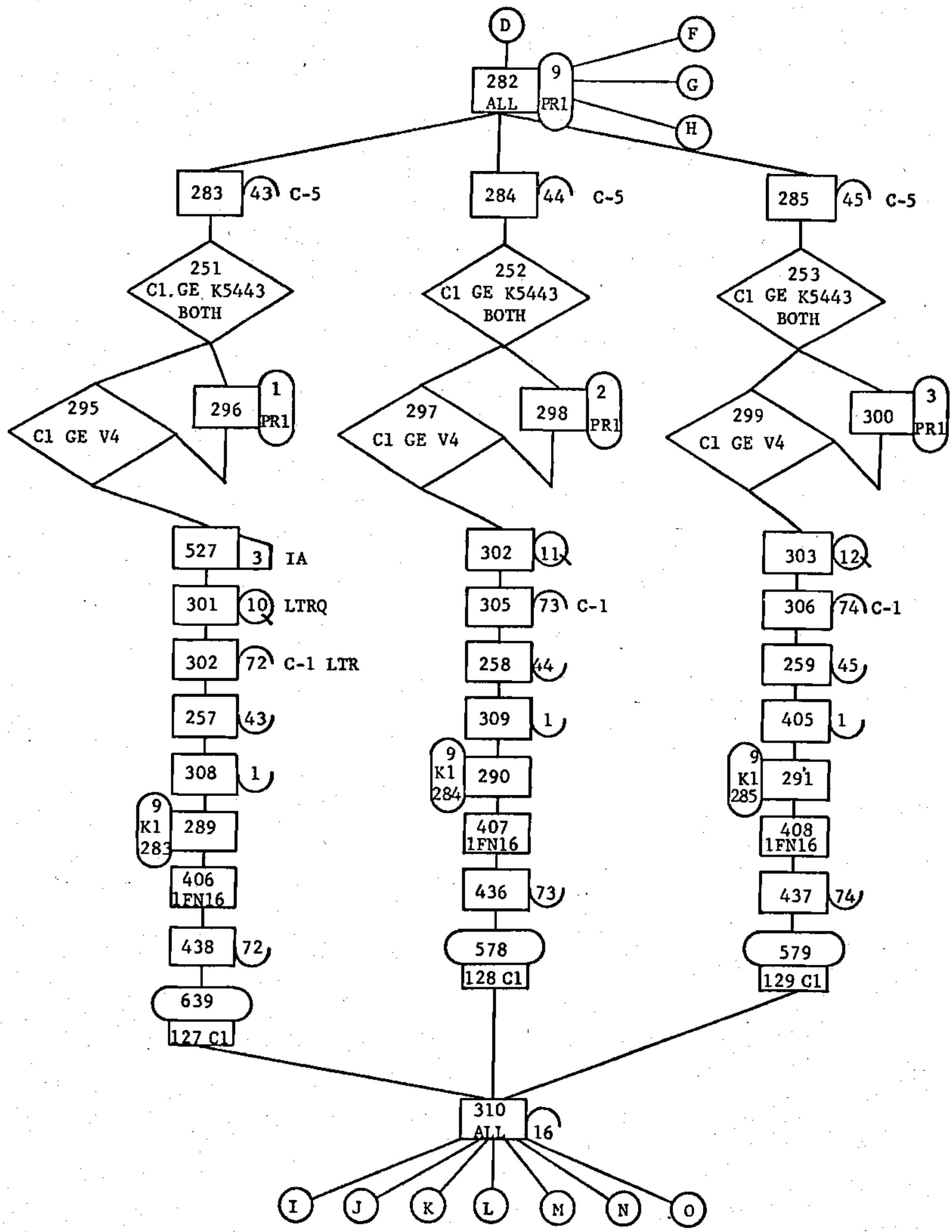


Figure 24. Continued

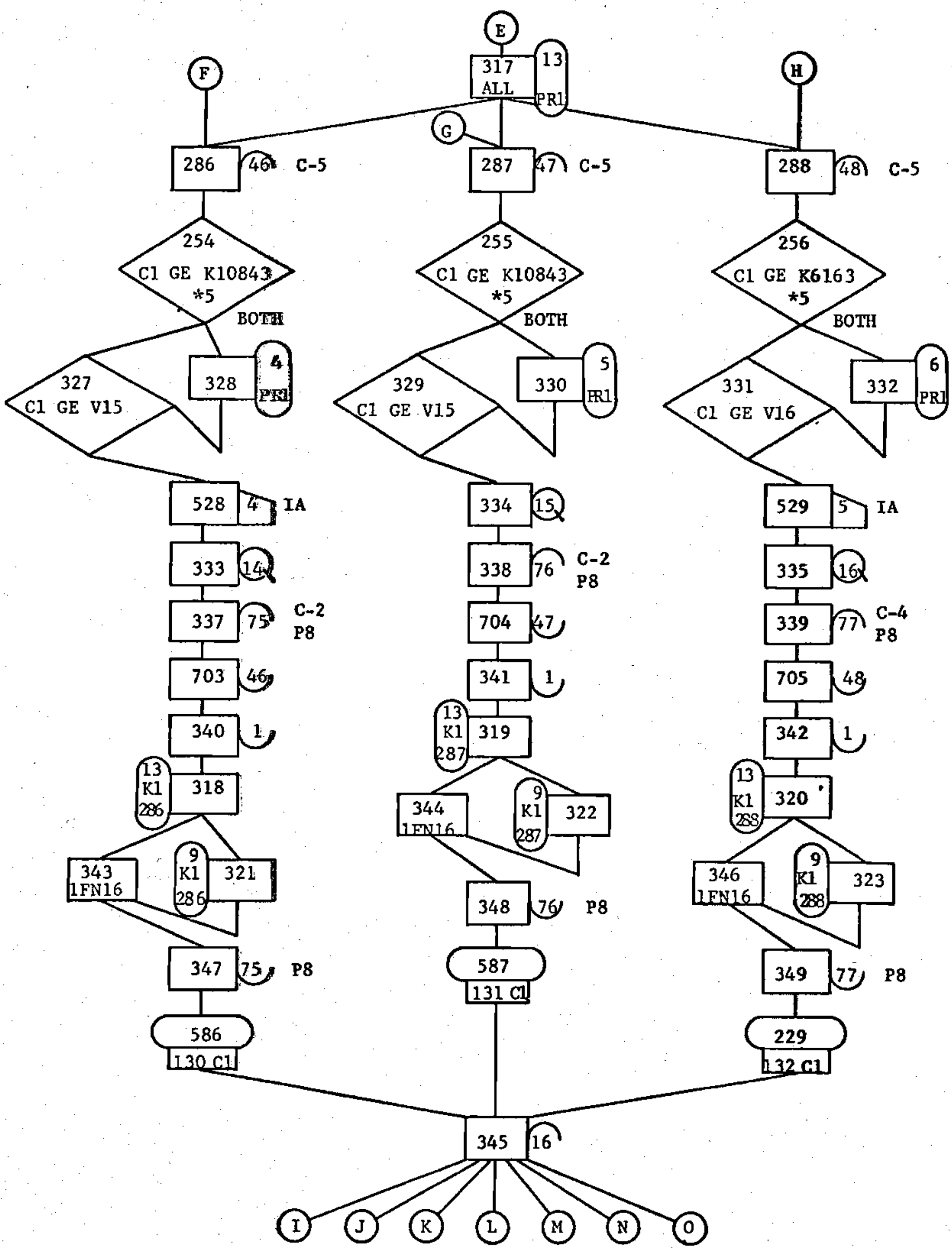


Figure 24. Concluded

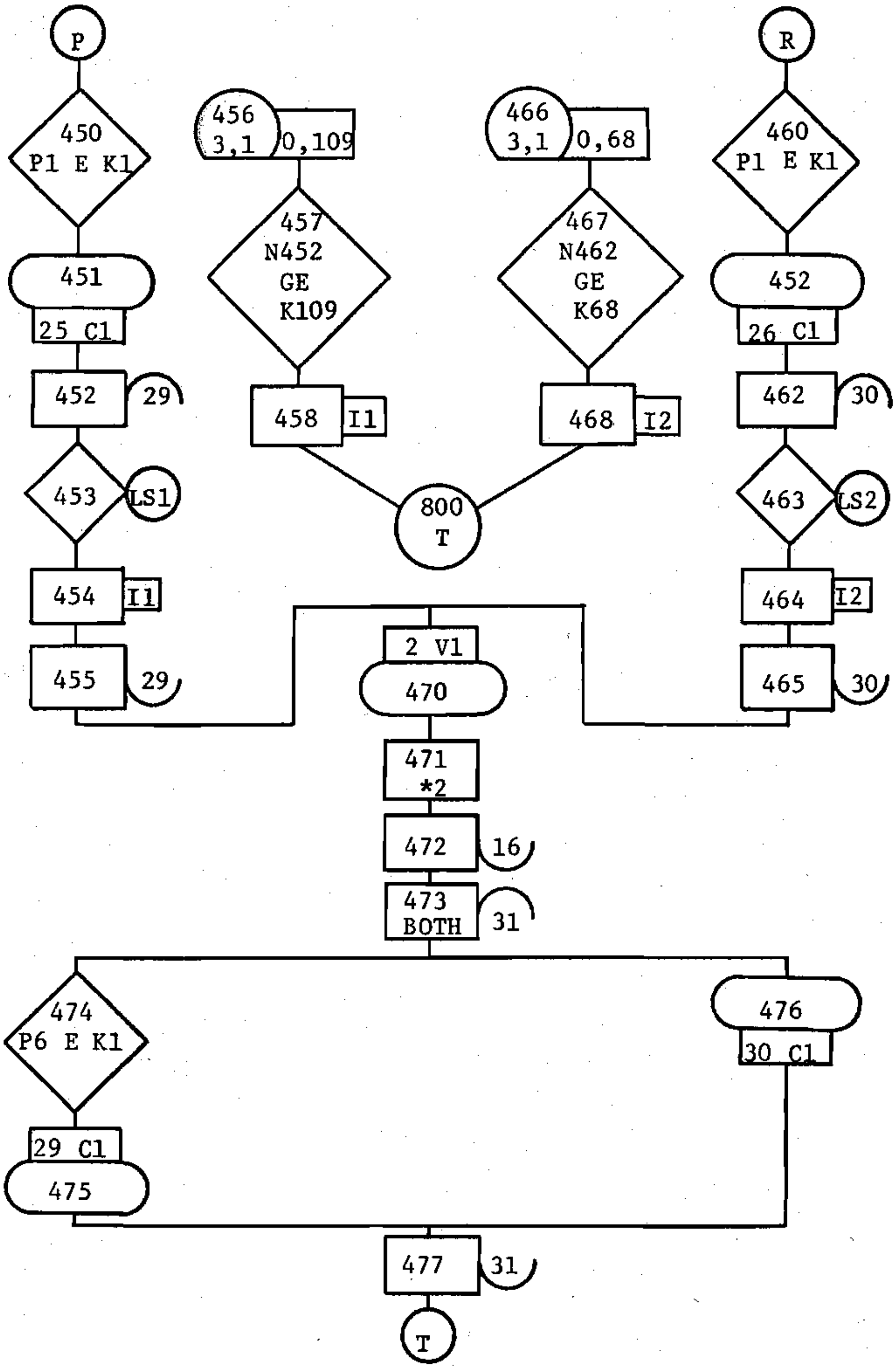


Figure 25. GPSS II Southern Amphibious Vehicle Flow, CAFB

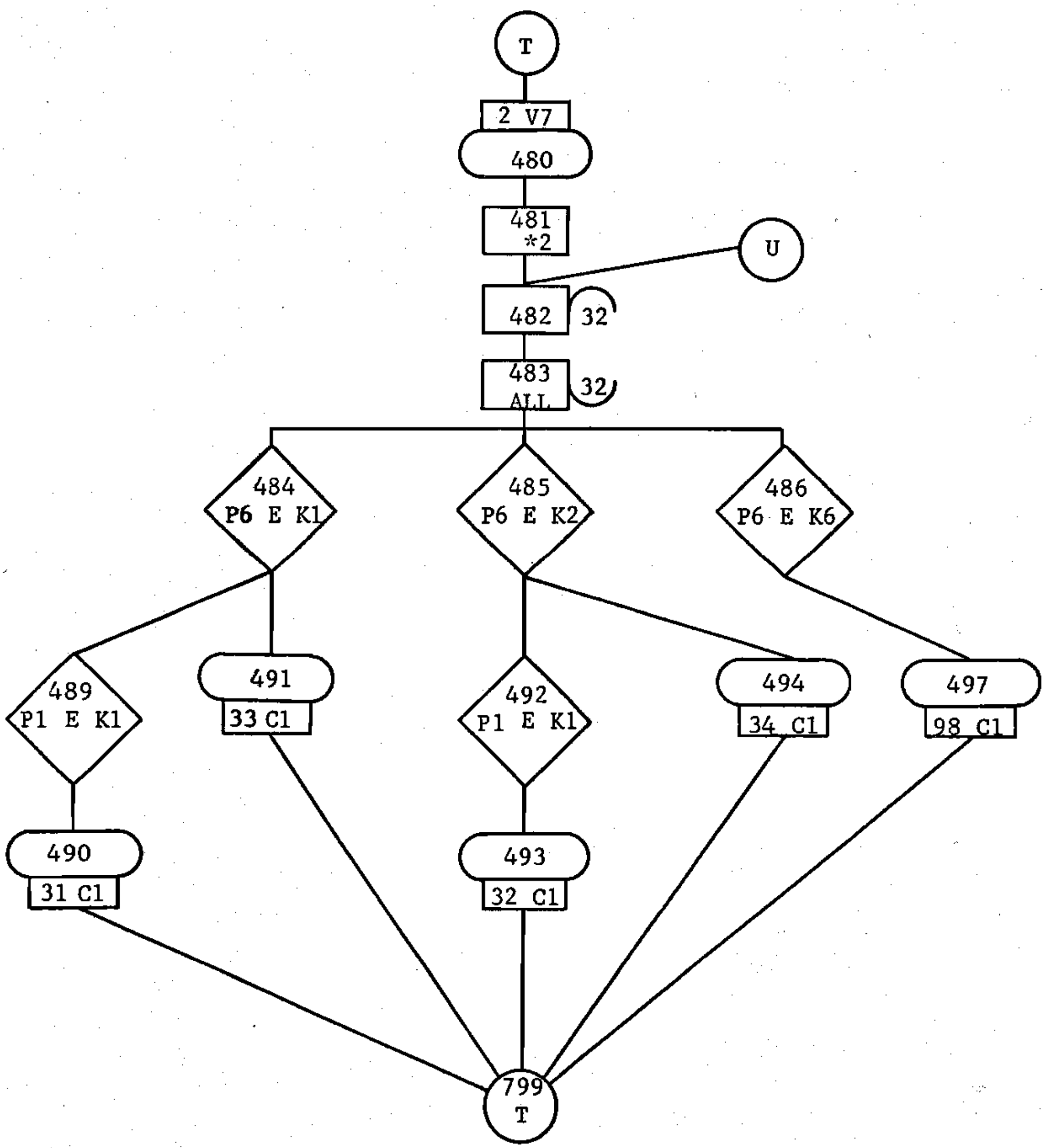


Figure 25. Concluded

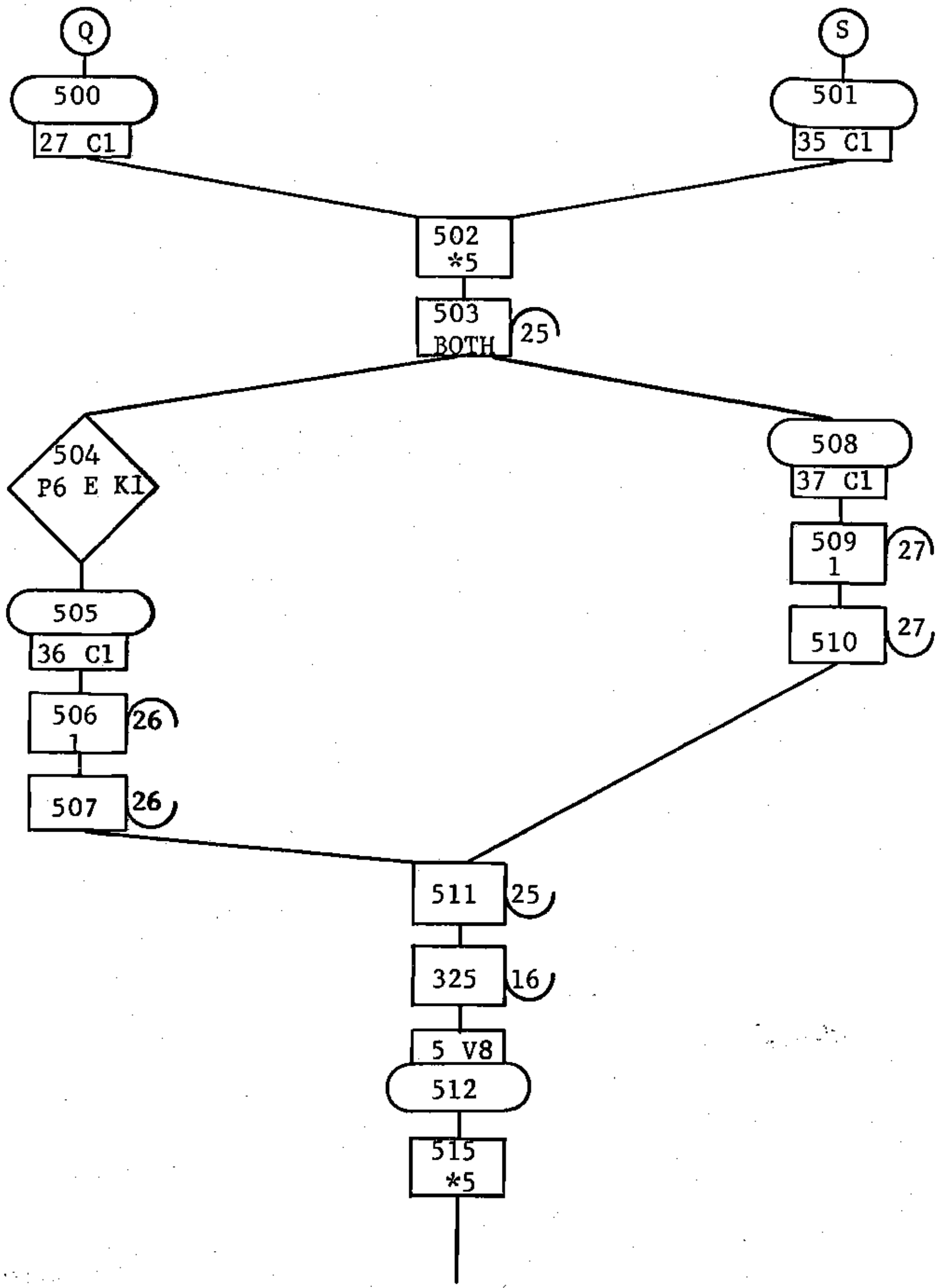


Figure 26. GPSS II Southern Nonamphibious Vehicle Flow, CAFB

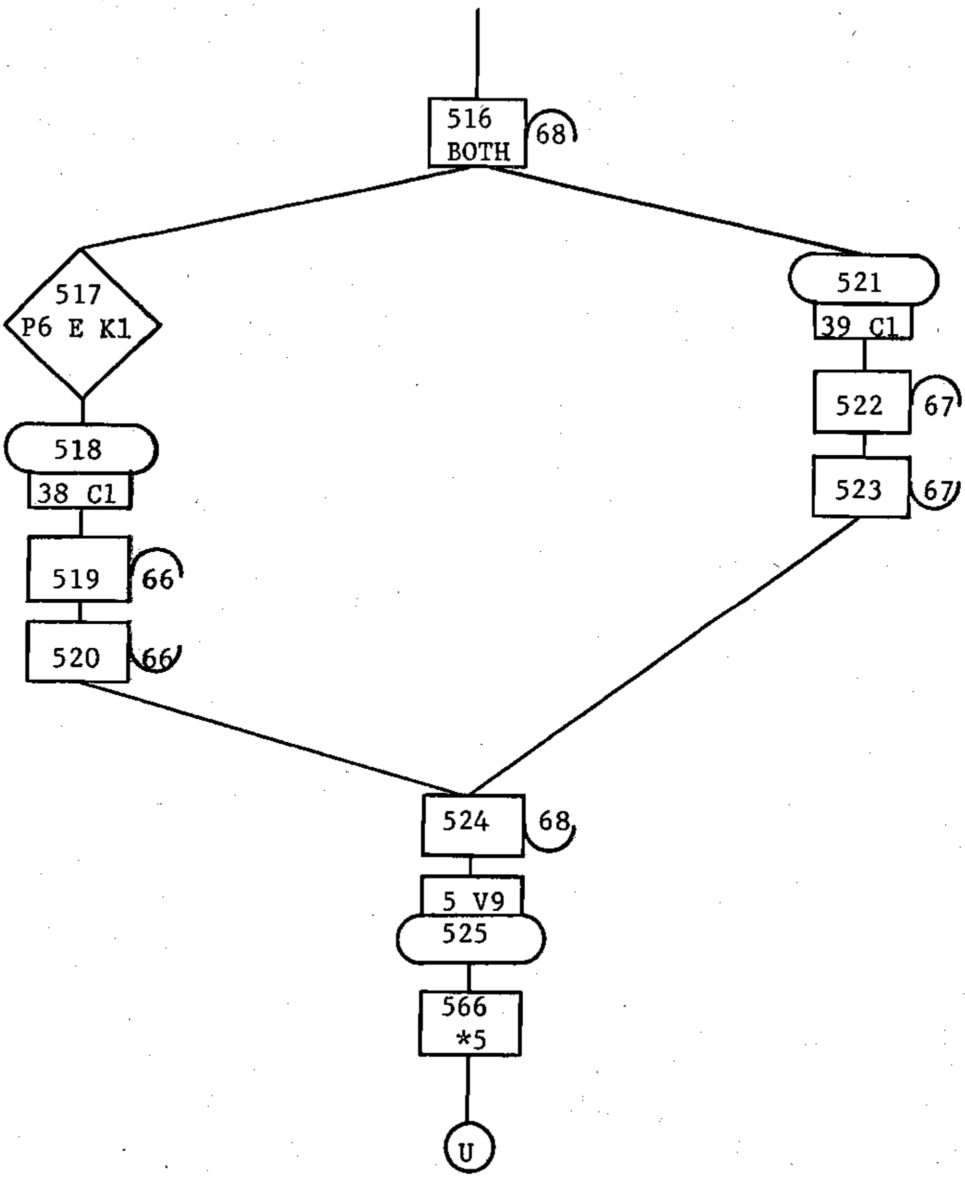


Figure 26. Concluded

APPENDIX E

GPSS II SIMULATION LANGUAGE

General Purpose Systems Simulator II is a special purpose simulation language which requires little or no previous programming experience to use (24). The language is ideally suited for simulating queueing flow problems. Transactions, representing units of traffic, are created and flow through the block diagram, which represents the system being simulated. The model of the system is constructed through the use of a flow chart which traces the movement of transactions from one block of the system to another. The blocks describe some specific step or response of the system.

Transactions are initiated by GENERATE or ORIGINATE blocks. These blocks enable one to initiate a specific number of transactions, to select the time the first transaction enters the system, to designate transaction interarrival times, and to assign transaction priorities.

The routing from a block is depicted by one or more straight lines drawn from the block to its successors. A block specifies the next block to which a transaction is to be sent upon completion of the designated action time at the block. Various selection modes are available that provide considerable flexibility in this routing.

Traffic movement--the movement of transactions through the block diagram--is controlled by a program clock. Each event occurs at a designated time. The program keeps a "current events" and "future events" list and moves transactions through the system in the correct time sequence. An event which is scheduled to occur at a specific time is processed until a delay or all events scheduled at that time have been completed. The master clock is incremented to the next scheduled event and the process continues until there are no more events to process.

While moving through a system, transactions are operated on or influenced by the equipment in the system. This equipment is represented by blocks, facilities, and storages.

Table 15. GPSS II System Representations

Type of System	Transaction	Facility	Storage
River Crossing Operation	Vehicle	Single Vehicle Load Raft	Multiple Vehicle Load Raft

Facilities may be used by one transaction; storages may be used by any preset number of transactions. The HOLD, SEIZE, and RELEASE blocks handle single transactions and are called unit processing elements. A raft may be represented by a HOLD block. One transaction (vehicle) enters the block if not occupied and is delayed for a time which simulates the raft's occupancy. The SEIZE and RELEASE block's use is similar to that of the HOLD block.

The STORE, ENTER, and LEAVE blocks are the batch processing elements analogous to the unit processing element blocks. A STORE block with a capacity of four could represent a large raft capable of carrying four vehicles. Transactions (vehicles) enter the STORE block until the capacity is reached and are delayed for a time which simulates the raft's occupancy.

Transactions refused entry to a block form queues. The queues are simulated by the QUEUE block which maintains statistics on the average queue delay, number of entries, and other pertinent information. These statistics are printed in a special section of the computer printout at the end of the simulation run.

TERMINATE blocks remove transactions from the system. As a transaction enters this block, the total number of transactions in the system is decremented by one.

Various statistics are constantly maintained by the program and, like the queue statistics, are printed out at the end of the run. Some of these statistics are storage utilization data, facility utilization data, number of transactions in the system, and the average length of time a transaction spends in the system. Detailed information on the UNIVAC 1108 GPSS II system can be found in (12).

APPENDIX F

REPRESENTATIVE MILITARY SYMBOLS

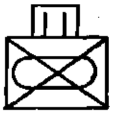
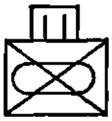
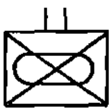
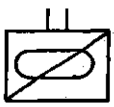
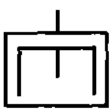
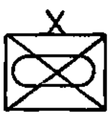
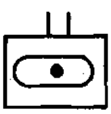
		1-77	Task force, 1st Battalion, 77th Infantry (Mechanized)
		1-4	Task force, 1st Battalion, 4th Armor
		1-76(-)	1st Battalion, 76th Infantry (Mechanized)(The (-) indicate one or more companies have been detached from the battalion.)
		1-23	1st Squadron, 23rd Armored Cavalry
A		52	A Company, 52nd Engineer Battalion
1		52	1st Brigade, 52nd Mechanized Division
		1-40	1st Battalion, 40th Artillery

Figure 27. Representative Military Symbols

BIBLIOGRAPHY

Literature Cited

1. Abele, Louis Edward, Use of Industrial Dynamics in the Simulation of Military Combat Models, M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1966.

2. Boles, Jimmie K., A GPSS II Simulation of an Air Defense Problem, M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1969.

3. Dalkey, Normon C., "Simulation of Military Conflict," RAND, P-3400, January, 1967.

4. Davis, Reed E., A Dynamo Simulation of an Assault River Crossing, M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1967.

5. Department of the Army, Catalog of Army War Games and Models, Office of the Deputy Chief of Staff for Operations, 1968.

6. ______________________, Dictionary of United States Army Terms, AR 320-5, 1967.

7. ______________________, The Division, FM 61-100, 1968.

8. ______________________, The Infantry Battalions, FM 7-20, 1969.

9. ______________________, River Crossing Operations, FM 31-60, 1966.

10. ______________________, Staff Officers' Field Manual, Organizational, Technical, and Logistics Data, FM 101-10-1, 1969.

11. Faulkender, Robert W., Use of Industrial Dynamics in Simulation of an Insurgent Activity, M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1967.

12. General Purpose Systems Simulator II Reference Manual, UNIVAC Data Processing Division, 1108 Multi-Processor System, 1970.

13. Gibson, Francis Lee, A GPSS II Model of a Logistic Transportation System, M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1969.

BIBLIOGRAPHY (Continued)

14. Ginsberg, A. S., "Simulation Programming and Analysis of Results," RAND, P-3141, May, 1965.

15. Gordon, Geoffrey, System Simulation, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1969.

16. Haverty, J. P., "GRAIL/GPSS: Graphic On-Line Modeling," RAND, P-3838, June, 1968.

17. Kiviat, P. J., "Digital Computer Simulation: Computer Programming Languages," RAND, RM-5883, 1969.

18. Kiviat, P. J., "Digital Computer Simulation: Modeling Concepts," RAND, RM-5378, 1967.

19. McLeod, John, (ed.), Simulation, McGraw-Hill Book Company, New York, 1968, p.3.

20. Meyer, Donald L., A Dynamo Simulation of a Complex Military Tactical Problem, M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1968.

21. Naylor, Thomas H., et. al., Computer Simulation Techniques, John Wiley and Sons, Inc., New York, 1966.

22. Naylor, Thomas H., (ed.), The Design of Computer Simulation Experiments, Duke University Press, Durham, North Carolina, 1969.

23. Quade, E. S., Analysis for Military Decisions, Rand McNally and Co., Chicago, 1966.

24. Schmidt, J. W., and Taylor, R. E., Simulation Analysis of Industrial Systems, Richard P. Irwin, Inc., Homewood, Illinois, 1970.

25. Smith John, Computer Simulation Models, Hafner Publishing Company, New York, 1968.

26. Steine, Joel Roger, A Simulation Model for Helicopter Maintenance Management, M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1968.

27. Published Report on the Second Conference on Applications of Simulation, December 2-4, New York, 1968.

28. U.S. Army Combat Developments Command, Catalog of Computerized Models, USACDC Pamphlet 71-11, 1969.

BIBLIOGRAPHY (Concluded)

29. U.S. Army Command and General Staff College, Deliberate and Hasty River Crossings, Instructional Problem M6440, 1968-69.

30. ______________________, War Gaming, Special Text 105-5-1, 1967.

31. U.S. Army Infantry School, Engineer Handbook, 1970.

32. ______________________, Infantry Reference Data, 1970.

33. ______________________, Logistics Handbook, 1970.

34. ______________________, River Crossing Operations, Instructional Problem BQC 74/1, 1971.

Other References

Conway, R. W., "Some Tactical Problems in Digital Simulation," Management Science, vol. 10, 1963, p.47-61.

Department of the Army, The Infantry Brigades, FM 7-30, 1969.

Geisler, Murray A., "The Simulation of a Large Scale Military Activity," RAND, P-1555, 1959.

Naylor, Thomas., and Finger, J. M., "Verification of Computer Simulation Models," Management Science, vol. 14, 1967, p.92-106.

Vail, Robert Bruce, Military Applications of Dynamo, M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 1968.

Walsh, John E., "Evaluation of Simulation From Its Ability to Simulate Components (Subsystems) of Overall System," Technical Report No. 56, Department of Statistics, THEMIS Contract, Southern Methodist University, Dallas, Texas, 1970.

Weiner, M. G., "Trends in Military Gaming," RAND, P-4173, 1969.